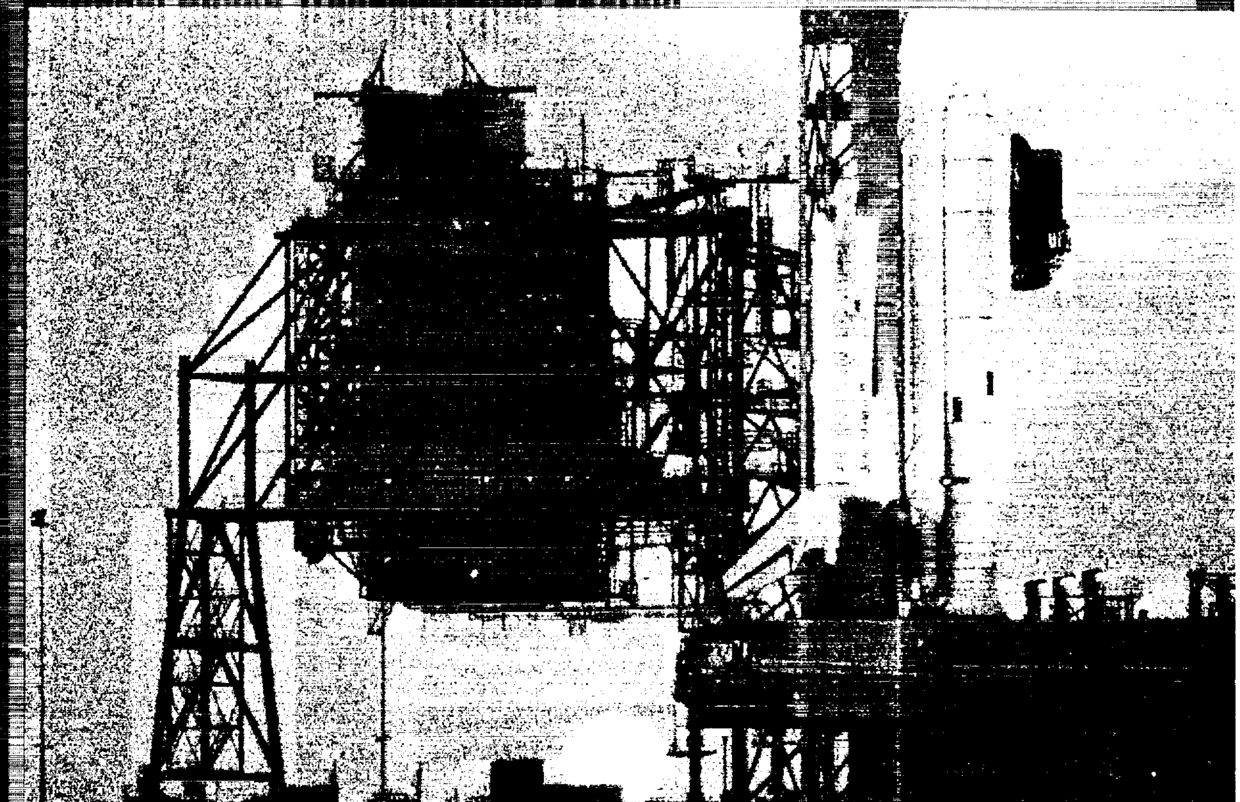
National Space Transportation System



Overview

September 1988

NASA

National Space Transportation System

Overview

September 1988

CONTENTS

SPACE SHUTTLE PROGRAM

The Space Shuttle is developed by the National Aeronautics and Space Administration. NASA coordinates and manages the Space Transportation System (NASA's name for the overall Shuttle program), including intergovernmental agency requirements and international and joint projects. NASA also oversees the launch and space flight requirements for civilian and commercial use.

The Space Shuttle system consists of four primary elements: an orbiter spacecraft, two Solid Rocket Boosters (SRB), an external tank to house fuel and oxidizer and three Space Shuttle main engines.

The orbiter is built by Rockwell International's Space Transportation Systems Division, Downey, Calif., which also has responsibility for the integration of the overall space transportation system. Both orbiter and integration contracts are under the direction of NASA's Johnson Space Center in Houston, Texas.

The SRB motors are built by the Wasatch Division of Morton Thiokol Corp., Brigham City, Utah, and are assembled, checked out and refurbished by United Space Boosters Inc., Booster Production Co., Kennedy Space Center, Cape Canaveral, Fla. The external tank is built by Martin Marietta Corp. at its Michoud facility, New Orleans, La., and the Space Shuttle main engines are built by Rockwell's Rocketdyne Division, Canoga Park, Calif. These contracts are under the direction of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

SPACE SHUTTLE REQUIREMENTS

The Shuttle will transport cargo into near Earth orbit 100 to 217 nautical miles (115 to 250 statute miles) above the Earth. This cargo -- or payload -- is carried in a bay 15 feet in diameter and 60 ft long.

Major system requirements are that the orbiter and the two solid rocket boosters be reusable.

Other features of the Shuttle:

The orbiter has carried a flight crew of up to eight persons. A total of 10 persons could be carried under emergency conditions The basic mission is 7 days in space. The crew compartment has a shirtsleeve environment, and the acceleration load is never greater than 3 Gs. In its return to Earth, the orbiter has a cross-range maneuvering capability of 1,100 nautical miles (1,265 statute miles).

The Space Shuttle is launched in an upright position, with thrust provided by the three Space Shuttle engines and the two SRB. After about 2 minutes, the two boosters are spent and are separated from the external tank. They fall into the ocean at predetermined points and are recovered for reuse.

	Overall Shuttle	Orbiter
Length	184.2 feet	122.17 feet
Height	76.6 feet	56.67 feet
Wingspan	–	78.06 feet
Approximate weight		
• Gross lift-off, which will vary depending on payload weight and onboard consumables	4.5 million pounds	–
• Nominal end-of-mission landing with payload, which will vary depending on payload return weight	–	230,000 pounds
Thrust (sea level)		
• Solid rocket boosters	3,300,000 pounds of thrust each in vacuum	–
• Orbiter main engines	–	393,800 pounds of thrust each at sea level at 104 percent
Cargo bay		
• Length	–	60 feet
• Diameter	–	15 feet

Space Shuttle Program

The Space Shuttle main engines continue firing for about 8 minutes. They shut down just before the craft is inserted into orbit. The external tank is then separated from the orbiter. It follows a ballistic trajectory into a remote area of the ocean but is not recovered.

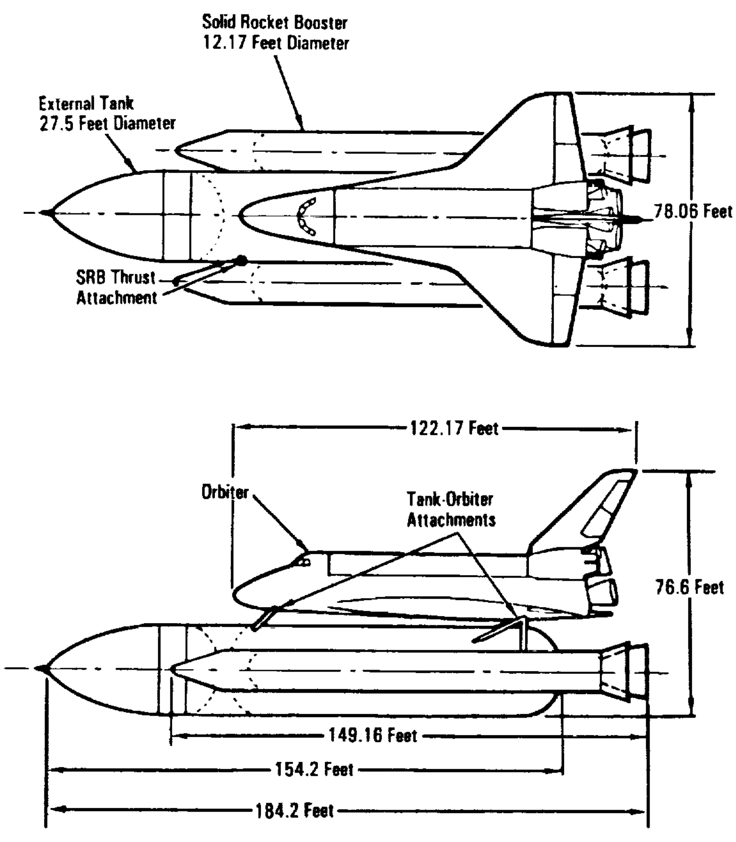
There are 38 primary Reaction Control System (RCS) engines and six vernier RCS engines located on the orbiter. The first use of selected primary reaction control system engines occurs at orbiter/external tank separation. The selected primary reaction control system engines are used in the separation sequence to provide an attitude hold for separation. Then they move the orbiter away from the external tank to ensure orbiter clearance from the arc of the rotating external tank. Finally, they return to an attitude hold prior to the initiation of the firing of the Orbital Maneuvering System (OMS) engines to place the orbiter into orbit.

The primary and/or vernier RCS engines are used normally on orbit to provide attitude pitch, roll and yaw maneuvers as well as translation maneuvers.

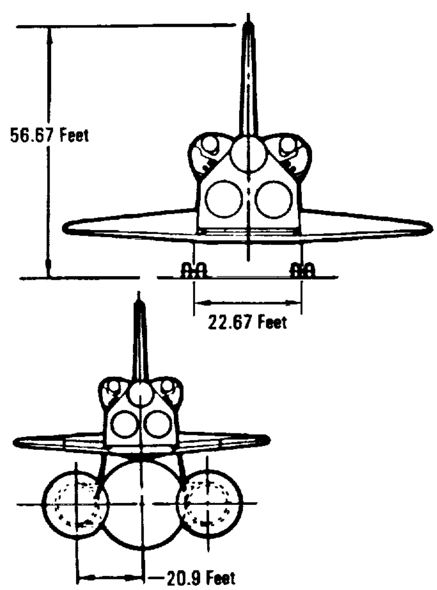
orbit, and only one thrusting sequence is used for deorbit.

The orbiter's velocity on orbit is approximately 25,405 feet per second (17,322 statute miles per hour). The deorbit maneuver decreases this velocity approximately 300 fps (205 mph) for reentry.

In some missions, only one OMS thrusting sequence is used to place the orbiter on orbit. This is referred to as direct insertion. Direct insertion is a technique used in some missions where there are high-performance requirements, such as a heavy



Orbiter Weight in Pounds (Approximate)		
Orbiter Vehicle (OV)	Total Dry Weight With Three Space Shuttle Main Engines	Total Dry Weight Without Three Space Shuttle Main Engines
OV-102 Columbia	178,289	157,289
OV-103 Discovery	171,419	151,419
OV-104 Atlantis	171,205	151,205
Solid Rocket Booster Weights in Pounds (Approximate)		
1,300,000, Each at Launch (Propellant Weight 1,100,000, Each). Inert Weight 192,000, Each.		
External Tank Weight in Pounds (Approximate)		
1,655,600 With Propellants. Inert Weight 66,000.		



Space Shuttle Statistics

The two OMS engines are used to place the orbiter on orbit, for major velocity maneuvers on orbit and to slow the orbiter for reentry, called the deorbit maneuver. Normally, two OMS engine thrusting sequences are used to place the orbiter on orbit.

payload or a high orbital altitude. This technique uses the Space Shuttle main engines to achieve the desired apogee (high point in an orbit) altitude, thus conserving orbital maneuvering system propellants. Following jettison of the external tank, only one OMS thrusting sequence is required to establish the desired orbit altitude.

For deorbit, the orbiter is rotated tail first in the direction of the velocity by the primary reaction control system engines. Then the OMS engines are used to decrease the orbiter's velocity.

During the initial entry sequence, selected primary RCS engines are used to control the orbiter's attitude (pitch, roll and yaw). As aerodynamic pressure builds up, the orbiter flight control surfaces become active and the primary reaction control system engines are inhibited.

During entry, the thermal protection system covering the entire orbiter provides the protection for the orbiter to survive the extremely high temperatures encountered during entry. The thermal protection system is reusable (it does not burn off or ablate during entry).

The unpowered orbiter glides to Earth and lands on a runway like an airplane. Nominal touchdown speed varies from 184 to 196 knots (213 to 225 miles per hour).

The main landing gear wheels have a braking system for stopping the orbiter on the runway, and the nose wheel is steerable, again similar to a conventional airplane.

There are two launch sites for the Space Shuttle. Kennedy Space Center (KSC) in Florida is used for launches to place the orbiter in equatorial orbits (around the equator), and Vandenberg Air Force Base launch site in California will be used for launches that place the orbiter in polar orbit missions.

Landing sites are located at the KSC and Vandenberg. Additional landing sites are provided at Edwards Air Force Base in California and White Sands, N.M. Contingency landing sites are also provided in the event the orbiter must return to Earth in an emergency.

LAUNCH SITES

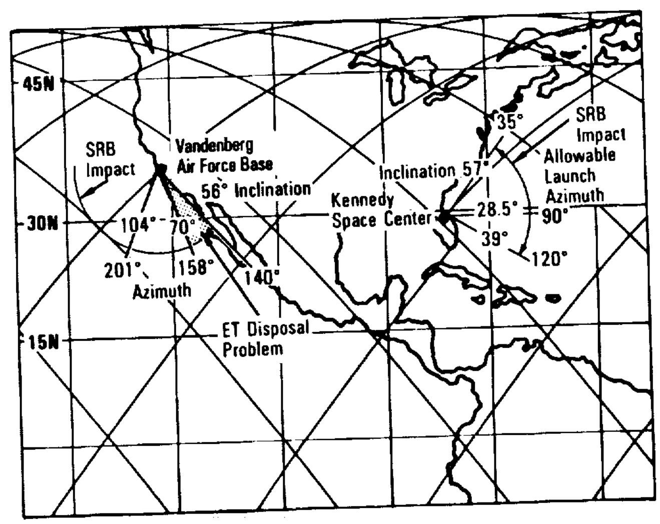
Space Shuttles destined for equatorial orbits are launched from the KSC, and those requiring polar orbital planes will be launched from Vandenberg.

Orbital mechanics and the complexities of mission requirements, plus safety and the possibility of infringement on foreign air and land space, prohibit polar orbit launches from the KSC.

Kennedy Space Center launches have an allowable path no less than 35 degrees northeast and no greater than 120 degrees southeast. These are azimuth degree readings based on due east from KSC as 90 degrees.

A 35-degree azimuth launch places the spacecraft in an orbital inclination of 57 degrees. This means the spacecraft in its orbital trajectories around the Earth will never exceed an Earth latitude higher or lower than 57 degrees north or south of the equator.

A launch path from KSC at an azimuth of 120 degrees will place the spacecraft in an orbital inclination of 39 degrees (it will be above or below 39 degrees north or south of the equator).



Space Shuttle Launch Sites

These two azimuths - 35 and 120 degrees - represent the launch limits from the KSC. Any azimuth angles further north or south would launch a spacecraft over a habitable land mass, adversely affect safety provisions for abort or vehicle separation conditions, or present the undesirable possibility that the SRB or external tank could land on foreign land or sea space.

Launches from Vandenberg have an allowable launch path suitable for polar insertions south, southwest and southeast.

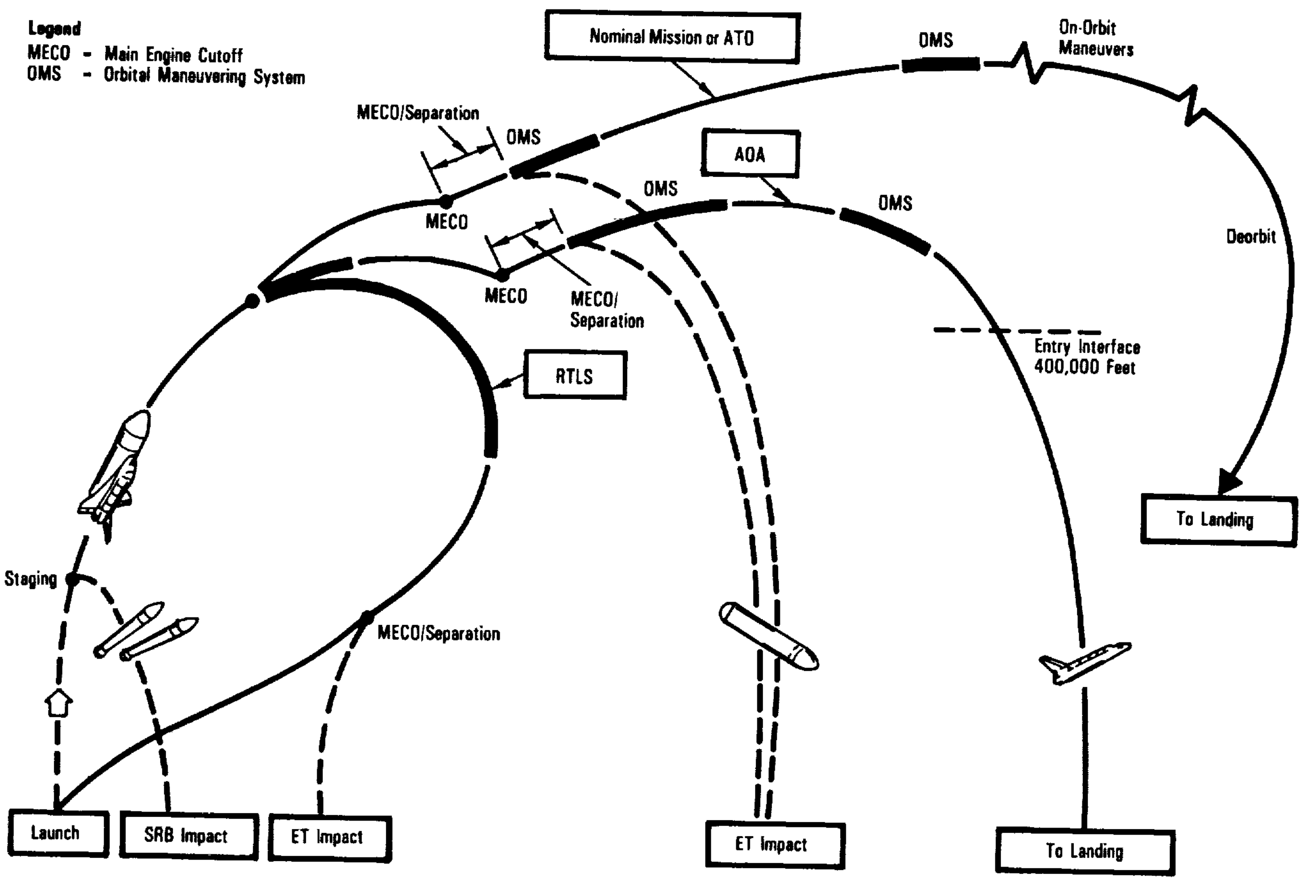
The launch limits at Vandenberg are 201 and 158 degrees. At a 201-degree launch azimuth, the spacecraft would be orbiting at a 104-degree inclination. Zero degrees would be due north of the launch site, and the orbital trajectory would be within 14 degrees east or west of the north-south pole meridian. At a launch azimuth of 158 degrees, the spacecraft would be orbiting at a 70-degree inclination, and the trajectory would be within 20 degrees east or west of the polar meridian. Like KSC, Vandenberg has allowable launch azimuths that do not pass over habitable areas or involve safety, abort, separation and political considerations.

Mission requirements and payload weight penalties also are major factors in selecting a launch site.

The Earth rotates from west to east at a speed of approximately 900 nautical miles per hour (1,035 mph). A launch to the east uses the Earth's

Attempting to launch and place a spacecraft in polar orbit from KSC to avoid habitable land mass would be uneconomical because the Shuttle's payload would be reduced severely-down to approximately 17,000 pounds. A northerly launch into polar orbit of 8 to 20 degrees azimuth would necessitate a path over a land mass; and most safety, abort, and political constraints would have to be waived. This prohibits polar orbit launches from the KSC.

NASA's latest assessment of orbiter ascent and landing weights incorporates currently



Abort and Normal Mission Profile

The Earth rotates from west to east at a speed of approximately 900 nautical miles per hour (1,035 mph). A launch to the east uses the Earth's rotation somewhat as a springboard. The Earth's rotational rate also is the reason the orbiter has a approved modifications to all vehicle elements, including crew escape provisions, and assumes a maximum Space Shuttle main engine throttle setting of 104 percent. It is noted that the resumption of Space Shuttle flights initially resumption of Space Shuttle flights initially requires more conservative flight design criteria and additional instrumentation, which reduces the following basic capabilities by approximately 1,600 pounds:

•Kennedy Space Center Eastern Space and Missile Center (ESMC) satellite deploy missions. The basic cargo-lift capability for a due east (28.5 degrees) launch is 55,000 pounds to a 110-nautical-mile (126-statute-mile) orbit using OV-103 (Discovery) or OV-104 (Atlantis) to support a 4-day satellite deploy mission. This capability will be reduced approximately 100 pounds for each additional nautical mile of altitude desired by the customer.

The payload capability for the same satellite deploy mission with a 57-degree inclination is 41,000 pounds.

The performance for intermediate inclinations can be estimated by allowing 500 pounds per degree of plane change between 28.5 and 57 degrees.

If OV-102 (Columbia) is used, the cargo-lift weight capability must be decreased by approximately 8,400 pounds. This weight difference is attributed to an approximately 7,150-pound difference in inert weight, 850 pounds of orbiter experiments, 300 pounds of additional thermal protection system and 100 pounds to accommodate a fifth cryogenic liquid oxygen and liquid hydrogen tank set for the power reactant storage and distribution system.

•Vandenberg Air Force Base Western Space and Missile Center (WSMC) satellite deploy missions. Using OV-103 (Discovery) or OV-104 (Atlantis), the cargo-lift weight capability is 29,600 pounds for a 98-degree launch inclination and 110-nautical-mile (126-statute-mile) polar orbit. Again, an increase in altitude costs approximately 100 pounds per nautical mile. NASA assumes also that the advanced solid rocket motor will replace the filament-wound solid rocket motor case previously used for western test range assessments. The same mission at 68 degrees inclination (minimum western test range inclination based on range safety limitations) is 49,600 pounds. Performance for intermediate inclinations can be estimated by allowing 660 pounds for each degree of plane change between inclinations of 68 and 98 degrees.

•Landing weight limits. All the Space Shuttle orbiters are currently limited to a total vehicle landing weight of 240,000 pounds for abort landings and 230,000 pounds for nominal end-of-mission landings. It is noted that each additional crew person beyond the five-person standard is chargeable to the cargo weight allocation and reduces the payload capability by approximately 500 pounds. (This is an increase of 450 pounds to account for the crew escape equipment.)

BACKGROUND AND STATUS

On July 26, 1972, NASA selected Rockwell's Space Transportation Systems Division in Downey, Calif., as the industrial contractor for the design, development, test and evaluation of the orbiter. The contract called for fabrication and testing of two orbiters, a full-scale structural test article, and a main propulsion test article. The award followed years of NASA and Air Force studies to define and assess the feasibility of a reusable space transportation system.

NASA previously (March 31, 1972) had selected Rockwell's Rocketdyne Division to design and develop the Space Shuttle main engines. Contracts followed to Martin Marietta for the external tank (Aug. 16, 1973) and Morton Thiokol's Wasatch Division for the solid rocket boosters (June 27, 1974).

In addition to the orbiter DDT&E contract, Rockwell's Space Transportation Systems Division was given contractual responsibility as system integrater for the overall Shuttle system.

Rockwell's Launch Operations, part of the Space Transportation Systems Division, was under contract to NASA's Kennedy Space Center for turnaround, processing, prelaunch testing, and launch and recovery operations from STS-1 through the STS-11 mission.

On Oct. 1, 1983, the Lockheed Space Operations Co. was awarded the Space Shuttle processing contract at KSC for turnaround processing, prelaunch testing, and launch and recovery operations.

The first orbiter spacecraft, Enterprise (OV-101), was rolled out on Sept. 17, 1976. On Jan. 31, 1977, it was transported 38 miles overland from Rockwell's assembly facility at Palmdale, Calif., to NASA's Dryden Flight Research Facility at Edwards Air Force Base for the Approach and Landing Test (ALT) program.

The 9-month-long ALT program was conducted from February through November 1977 at Dryden and demonstrated the orbiter could fly in the atmosphere and land like an airplane except without power, a gliding flight.

The ALT program involved ground tests and flight tests.

The ground tests included taxi tests of the 747 Shuttle Carrier Aircraft (SCA) with the Enterprise mated atop the SCA to determine structural loads and responses and assess the mated capability in ground handling and control characteristics up to flight takeoff speed. The taxi tests also validated 747 steering and braking with the orbiter attached. A ground test of orbiter systems followed the unmanned captive tests. All orbiter systems were activated as they would be in atmospheric flight. This was the final preparation for the manned captive-flight phase.

Five captive flights of the Enterprise mounted atop the SCA with the Enterprise unmanned and Enterprise systems inert were conducted to assess the structural integrity and performance-handling qualities of the mated craft.

Three manned captive flights that followed the five unmanned captive flights included an astronaut crew aboard the orbiter operating its flight control systems while the orbiter remained perched atop the SCA. These flights were designed to exercise and evaluate all systems in the flight environment in preparation for the orbiter release (free) flights. They included flutter tests of the mated craft at low and high speed, a separation trajectory test and a dress rehearsal for the first orbiter free flight.

In the five free flights the astronaut crew separated the spacecraft from the SCA and maneuvered to a landing at Edwards Air Force Base. In the first four such flights the landings were on a dry lake bed; in the fifth, the landing was on Edwards' main concrete runway under conditions simulating a return from space. The last two free flights were made without the tail cone, which is the spacecraft's configuration during an actual landing from Earth orbit. These flights verified the orbiter's pilot-guided approach and landing capability; demonstrated the orbiter's subsonic terminal area energy management autoland approach capability; and verified the orbiter's subsonic airworthiness, integrated system operations and selected subsystems in preparation for the first manned orbital flight. The flights demonstrated the orbiter's ability to approach and land safely with a minimum gross weight and using several center-of-gravity

For all of the captive flights and the first three free flights, the orbiter was outfitted with a tail cone covering its aft section to reduce aerodynamic drag and turbulence. The final two free flights were without the tail cone, and the three simulated Space Shuttle main engines and two orbital maneuvering system engines were exposed aerodynamically.

The final phase of the ALT program prepared the spacecraft for four ferry flights. Fluid systems were drained and purged, the tail cone was reinstalled and elevon locks were installed.

The forward attachment strut was replaced to lower the orbiter's cant from 6 to 3 degrees. This reduces drag to the mated vehicles during the ferry flights.

After the ferry flight tests, OV-101 was returned to the NASA hangar at Dryden and modified for vertical ground vibration tests at NASA's Marshall Space Flight Center, Huntsville, Ala.

On March 13, 1978, the Enterprise was ferried atop the SCA to MSFC. At Marshall, Enterprise was mated with the external tank and SRB and subjected to a series of vertical ground vibration tests. These tested the mated configuration's critical structural dynamic response modes, which were assessed against analytical math models used to design the various element interfaces.

These were completed in March 1979. On April 10, 1979 the Enterprise was ferried to Kennedy Space Center, mated with the external tank and SRB and transported via the mobile launcher platform to Launch Complex 39-A. At

Launch Complex 39-A, the Enterprise served as a practice and launch complex fit-check verification tool representing the flight vehicles.

It was ferried back to Dryden at Edwards AFB in California on Aug. 16, 1979, and then returned overland to Rockwell's Palmdale final assembly facility on Oct. 30, 1979. Certain components were refurbished for use on flight vehicles being assembled at Palmdale. The Enterprise was then returned overland to Dryden on Sept. 6, 1981.

During exhibition at the Paris, May and June 1983, Enterprise was ferried to France for the Air Show as well as to Germany, Italy, England and Canada before returning to Dryden.

From April to October 1984, Enterprise was ferried to Vandenberg AFB and to Mobile, Ala., where it was taken by barge to New Orleans, La., for the United States 1984 World's Fair.

In November 1984 it was transported to Vandenberg and used as a practice and fit-check verification tool. On May 24, 1985, Enterprise was ferried from Vandenberg to Dryden.

On Sept. 20, 1985, Enterprise was ferried from Dryden Flight Research Facility to KSC. On Nov. 18, 1985, Enterprise was ferried from KSC to Dulles Airport, Washington, D.C., and became the property of the Smithsonian Institution. The Enterprise was built as a test vehicle and is not equipped for space flight.

The second orbiter, Columbia (OV-102), was the first to fly into space. it was transported overland on March 8, 1979, from Palmdale to Dryden for mating atop the SCA and ferried to KSC. It arrived on March 25, 1979, to begin preparations for the first flight into space.

The structural test article, after 11 months of extensive testing at Lockheed's facility in Palmdale, was returned to Rockwell's Palmdale facility for modification to become the second orbiter available for operational missions. it was redesignated OV-099, the Challenger.

The main propulsion test article (MPTS-098) consisted of an orbiter aft fuselage, a truss arrangement that simulated the orbiter's mid-fuselage and the Shuttle main propulsion system (three Space Shuttle main engines and the external tank). This test structure is at the Stennis Space Center in Mississippi. A series of static firings was conducted from 1978 through 1981 in support of the first flight into space.

On Jan. 29, 1979, NASA contracted with Rockwell to manufacture two additional orbiters, OV-103 and OV-104 (Discovery and Atlantis), convert the structural test article to space flight configuration (Challenger) and modify Columbia from its development configuration to that required for operational flights.

NASA named the first four orbiter spacecraft after famous exploration sailing ships. In the order they became operational, they are: Columbia (OV-102), after a sailing frigate launched in 1836, one of the first Navy ships to circumnavigate the globe. Columbia also was the name of the Apollo 11 command module that carried Neil Armstrong, Michael Collins and Edward (Buzz) Aldrin on the first lunar landing mission, July 20, 1969. Columbia was delivered to Rockwell's Palmdale assembly facility for modifications on Jan. 30, 1984, and was returned to KSC on July 14, 1985, for return to flight. Challenger (OV-099), also a Navy ship, which from 1872 to 1876 made a prolonged exploration of the Atlantic and Pacific oceans. It also was used in the Apollo program for the Apollo 17 lunar module. Challenger was delivered to DSC on July 5, 1982. Discovery (OV-103), after two ships, the vessel in which Henry Hudson in 1610-11 attempted to search for a northwest passage between the Atlantic and Pacific oceans and instead discovered Hudson Bay and the ship in which Capt. Cook discovered the Hawaiian Islands and explored southern Alaska and western Canada. Discovery was delivered to KSC on Nov. 9, 1983. Atlantis (OV-104), after a two-masted ketch operated for the Woods Hole Oceanographic Institute from 1930 to 1966, which traveled more than half a million miles in ocean research. Atlantis was delivered to KSC on April 3, 1985.

In April 1983, under contract to NASA, Rockwell's Space Transportation Systems Division, Downey, Calif., began the construction of structural spares for completion in 1987. The structural spares program consisted of an aft fuselage, crew compartment, forward reaction control system, lower and upper forward fuselage, mid-fuselage, wings (elevons), payload bay doors, vertical stabilizer (rudder/speed brake), body flap and one set of orbital maneuvering system/reaction control system pods.

On Sept. 12, 1985, Rockwell International's Shuttle Operations Co., Houston, Texas, was awarded the Space Transportation System operation contract at NASA's Johnson Space Center, consolidating work previously performed under 22 contracts by 16 different contractors.

On July 31, 1987, NASA awarded Rockwell's Space Transportation Systems Division, Downey, Calif., a contract to build a replacement Space Shuttle orbiter using the structural spares. The replacement orbiter will be assembled at Rockwell's Palmdale, Calif., assembly facility and is scheduled for completion in 1991. This orbiter is designated OV-105.

MISSION PROFILE

In the launch configuration, the orbiter and two SRBs are attached to the external tank in a vertical (nose-up) position on the launch pad. Each SRB is attached at its aft skirt to the mobile launcher platform by four bolts.

Emergency exit for the flight crew on the launch pad up to 30 seconds before liftoff is by slidewire. There are seven 1,200-foot-long slidewires, each with one basket. Each basket is designed to carry three persons. The baskets, 5 feet in diameter and 42 inches deep, are suspended beneath the slide mechanism by four cables. The slidewires carry the baskets to ground level. Upon departing the basket at ground level, the flight crew progresses to a bunker that is designed to protect it from an explosion on the launch pad.

At launch, the three Space Shuttle main engines - fed liquid hydrogen fuel and liquid oxygen oxidizer from the external tank - are ignited first. When it has been verified that the engines are operating at the proper thrust level, a signal is sent to ignite the SRB. At the proper thrust-to-weight ratio, initiators (small explosives) at eight hold-down bolts on the SRB are fired to release the Space Shuttle for liftoff. All this takes only a few seconds.

Maximum dynamic pressure is reached early in the ascent, nominally approximately 60 seconds after liftoff. Approximately 1 minute later (2 minutes into the ascent phase), the two SRB have consumed their propellant and are jettisoned from the external tank. This is triggered by a separation signal from the orbiter.

The boosters briefly continue to ascend, while small motors fire to carry them away from the Space Shuttle. The boosters then turn and descend, and at a predetermined altitude, parachutes are deployed to decelerate them for a safe splashdown in the ocean. Splashdown occurs approximately 141 nautical miles (162 statute miles) from the launch site. The boosters are recovered and reused.

Meanwhile, the orbiter and external tank continue to ascend, using the thrust of the three Space Shuttle main engines. Approximately 8 minutes after launch and just short of orbital velocity, the three Space Shuttle engines are shut down (main engine cutoff), and the external tank is jettisoned on command from the orbiter.

The forward and aft reaction control system engines provide attitude (pitch, yaw and roll) and the translation of the orbiter away from the external tank at separation and return to attitude hold prior to the orbital maneuvering system thrusting maneuver.

The external tank continues on a ballistic trajectory and enters the atmosphere, where it disintegrates. Its projected impact is in the Indian Ocean (except for 57-degree inclinations) in the case of equatorial orbits KSC launch) and in the extreme southern Pacific Ocean in the case of a Vandenberg launch.

Normally, two thrusting maneuvers using the two OMS engines at the aft end of the orbiter are used in a two-step thrusting sequence: to complete insertion into Earth orbit and to circularize the spacecraft's orbit. The OMS engines are also used on orbit for any major velocity changes.

In the event of a direct-insertion mission, only one OMS thrusting sequence is used.

The orbital altitude of a mission is dependent upon that mission. The nominal altitude can vary between 100 to 217 nautical miles (115 to 250 statute miles).

The forward and aft RCS thrusters (engines) provide attitude control of the orbiter as well as any minor translation maneuvers along a given axis on orbit.

At the completion of orbital operations, the orbiter is oriented in a tail first attitude by the reaction control system. The two OMS engines are commanded to slow the orbiter for deorbit.

The reaction control system turns the orbiter's nose forward for entry. The reaction control system controls the orbiter until atmospheric density is sufficient for the pitch and roll aerodynamic control surfaces to become effective.

Entry interface is considered to occur at 400,000 feet altitude approximately 4,400 nautical miles (5,063 statute miles) from the landing site and at approximately 25,000 feet per second velocity.

At 400,000 feet altitude, the orbiter is maneuvered to zero degrees roll and yaw (wings level) and at a predetermined angle of attack for entry. The angle of attack is 40 degrees. The flight control system issues the commands to roll, pitch and yaw reaction control system jets for rate damping.

The forward RCS engines are inhibited prior to entry interface, and the aft reaction control system engines maneuver the spacecraft until a dynamic pressure of 10 pounds per square foot is sensed, which is when the orbiter's ailerons become effective. The aft RCS roll engines are then deactivated. At a dynamic pressure of 20 pounds per square foot, the orbiter's elevators become active, and the aft RCS pitch engines are deactivated. The orbiter's speed brake is used below Mach 10 to induce a more positive downward elevator trim deflection. At approximately Mach 3.5, the rudder becomes activated, and the aft reaction control system yaw engines are deactivated at 45,000 feet.

Entry guidance must dissipate the tremendous amount of energy the orbiter possesses when it enters the Earth's atmosphere to assure that the orbiter does not either burn up (entry angle too steep) or skip out of the atmosphere (entry angle too shallow) and that the orbiter is properly positioned to reach the desired touchdown point.

During entry, energy is dissipated by the atmospheric drag on the orbiter's surface. Higher atmospheric drag levels enable faster energy dissipation with a steeper trajectory. Normally, the angle of attack and roll angle enable the atmospheric drag of any flight vehicle to be controlled. However, for the orbiter, angle of attack was rejected because it creates surface temperatures above the design specification. The angle of attack scheduled during entry is loaded into the orbiter computers as a function of relative velocity, leaving roll angle for energy control. Increasing the roll angle decreases the vertical component of lift, causing a higher sink rate and energy dissipation rate. Increasing the roll rate does raise the surface temperature of the orbiter, but not nearly as drastically as an equal angle of attack command.

If the orbiter is low on energy (current range-to-go much greater than nominal at current velocity), entry guidance will command lower than nominal drag levels. If the orbiter has too much energy (current range-to-go much less than nominal at the current velocity), entry guidance will command higher-than-nominal drag levels to dissipate the extra energy.

Roll angle is used to control cross range. Azimuth error is the angle between the plane containing the orbiter's position vector and the heading alignment cylinder tangency point and the plane containing the orbiter's position vector and velocity vector. When the azimuth error exceeds a computer-loaded number, the orbiter's roll angle is reversed.

Thus, descent rate and down ranging are controlled by bank angle. The steeper the bank angle, the greater the descent rate and the greater the drag. Conversely, the minimum drag attitude is wings level. Cross range is controlled by bank reversals.

The entry thermal control phase is designed to keep the backface temperatures within the design limits. A constant heating rate is established until below 19,000 feet per second.

The equilibrium glide phase shifts the orbiter from the rapidly increasing drag levels of the temperature control phase to the constant drag level of the constant drag phase. The equilibrium glide flight is defined as flight in which the flight path angle, the angle between the local horizontal and the local velocity vector, remains constant.

Equilibrium glide flight provides the maximum downrange capability. It lasts until the drag acceleration reaches 33 feet per second squared.

The constant drag phase begins at that point. The angle of attack is initially 40 degrees, but it begins to ramp down in this phase to approximately 36 degrees by the end of this phase.

In the transition phase, the angle of attack continues to ramp down, reaching the approximately 14-degree angle of attack at the entry Terminal Area Energy Management (TAEM) interface, at approximately 83,000 feet altitude, 2,500 feet per second, Mach 2.5 and 52 nautical miles (59 statute miles) from the landing runway. Control is then transferred to TAEM guidance.

During the entry phases described, the orbiter's roll commands keep the orbiter on the drag profile and control cross range.

TAEM guidance steers the orbiter to the nearest of two heading alignment cylinders, whose radii are approximately 18,000 feet and which are located tangent to and on either side of the runway centerline on the approach end. In TAEM guidance, excess energy is dissipated with an S-turn; and the speed brake can be used to modify drag, lift-to-drag ratio and flight path angle in high-energy conditions. This increases the ground track range as the orbiter turns away from the nearest Heading Alignment Circle (HAC) until sufficient energy is dissipated to allow a normal approach and landing guidance phase capture, which begins at 10,000 feet altitude. The orbiter also can be flown near the velocity for maximum lift over drag or wings level for the range stretch case. The spacecraft slows to subsonic velocity at approximately 49,000 feet altitude, about 22 nautical miles (25.3 statute miles) from the landing site.

At TAEM acquisition, the orbiter is turned until it is aimed at a point tangent to the nearest HAC and continues until it reaches way point 1. At WP-1, the TAEM heading alignment phase begins. The HAC is followed until landing runway alignment, plus or minus 20 degrees, has been achieved. In the TAEM pre-final phase, the orbiter leaves the HAC; pitches down to acquire the steep glide slope, increases airspeed; banks to acquire the runway centerline and continues until on the runway centerline, on the outer glide slope and on airspeed. The approach and landing guidance phase begins with the completion of the TAEM pre-final phase and ends when the spacecraft comes to a complete stop on the runway.

The approach and landing trajectory capture phase begins at the TAEM interface and continues to guidance lock-on to the steep outer glide slope. The approach and landing phase begins at about 10,000 feet altitude at an equivalent airspeed of 290, plus or minus 12, knots 6.9 nautical miles (7.9 statute miles) from touchdown. Autoland guidance is initiated at this point to guide the orbiter to the minus 19- to 17-degree glide slope (which is over seven times that of a commercial airliner's approach) aimed at a target 0.86 nautical mile (1 statute mile) in front of the runway. The spacecraft's speed brake is positioned to hold the proper velocity. The descent rate in the later portion of TAEM and approach and landing is greater than 10,000 feet per minute (a rate of descent approximately 20 times higher than a commercial airliner's standard 3-degree instrument approach angle).

At 1,750 feet above ground level, a pre-flare maneuver is started to position the spacecraft for a 1.5-degree glide slope in preparation for landing with the speed brake positioned as required. The flight crew deploys the landing gear at this point.

The final phase reduces the sink rate of the spacecraft to less than 9 feet per second. Touchdown occurs approximately 2,500 feet past the runway threshold at a speed of 184 to 196 knots (213 to 226 mph).

ABORTS. Selection of an ascent abort mode may become necessary if there is a failure that affects vehicle performance, such as the failure of a Space Shuttle main engine or an orbital maneuvering system. Other failures requiring early termination of a flight, such as a cabin leak, might require the selection of an abort mode.

There are two basic types of ascent abort modes for Space Shuttle missions: intact aborts and contingency aborts. Intact aborts are designed to provide a safe return of the orbiter to a planned landing site. Contingency aborts are designed to permit flight crew survival following more sever failures when an intact abort is not possible. A contingency abort would generally result in a ditch operation.

There are four types of intact aborts: Abort to Orbit (ATO), Abort Once Around (AOA), Transatlantic Landing (TAL) and Return to Launch Site (RTLS).

The ATO mode is designed to allow the vehicle to achieve a temporary orbit that is lower than the nominal orbit. This mode requires less performance and allows time to evaluate problems and then choose either an early deorbit maneuver or an orbital maneuvering system thrusting maneuver to raise the orbit and continue the mission.

The AOA is designed to allow the vehicle to fly once around the Earth and make a normal entry and landing. This mode generally involves two orbital maneuvering system thrusting sequences, with the second sequence being a deorbit maneuver. The entry sequence would be similar to a normal entry.

The TAL mode is designed to permit an intact landing on the other side of the Atlantic Ocean. This mode results in a ballistic trajectory, which does not require an orbital maneuvering system maneuver.

The RTLS mode involves flying downrange to dissipate propellant and then turning around under power to return directly to a landing at or near the launch site.

There is a definite order of preference for the various abort modes. The type of failure and the time of the failure determine which type of abort is selected. In cases where performance loss is the only factor, the preferred modes would be ATO, AOA, TAL and RTLS, in that order. The mode chosen is the highest one that can be completed with the remaining vehicle performance. In the case of some support system failures, such as cabin leaks or vehicle cooling problems, the preferred mode might be the one that will end the mission most quickly. In these cases, TAL or RTLS might be preferable to AOA or ATO. A contingency abort is never chosen if another abort option exists.

The Mission Control Center-Houston is prime for calling these aborts because it has a more precise knowledge of the orbiter's position than the crew can obtain from onboard systems. Before main engine cutoff, Mission Control makes periodic calls to the crew to tell them which abort mode is (or is not) available. If ground communications are lost, the flight crew has onboard methods, such as cue cards, dedicated displays and display information, to determine the current abort region.

Which abort mode is selected depends on the cause and timing of the failure causing the abort and which mode is safest or improves mission success. If the problem is a Space Shuttle main engine failure, the flight crew and Mission Control Center select the best option available at the time a space shuttle main engine fails.

If the problem is a system failure that jeopardizes the vehicle, the fastest abort mode that results in the earliest vehicle landing is chosen. RTLS and TAL are the quickest options (35 minutes), whereas an AOA requires approximately 90 minutes. Which of these is elected depends on the time of the failure with three good Space Shuttle main engines.

The flight crew selects the abort mode by positioning an abort mode switch and depressing an abort push button.

RETURN TO LAUNCH SITE. The RTLS abort mode is designed to allow the return of the orbiter, crew, and payload to the launch site, Kennedy Space Center, approximately 25 minutes after lift-off. The RTLS profile is designed to accommodate the loss of thrust from one space shuttle main engine between liftoff and approximately four minutes 20 seconds, at which time not enough main propulsion system propellant remains to return to the launch site.

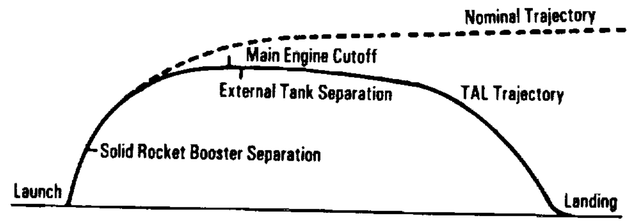
An RTLS can be considered to consist of three stages -- a powered stage, during which the main engines are still thrusting; an ET separation phase; and the glide phase, during which the orbiter glides to a landing at the KSC. The powered RTLS phase begins with the crew selection of the RTLS abort, which is done after SRB separation. The crew selects the abort mode by positioning the abort rotary switch to RTLS and depressing the abort push button. The time at which the RTLS is selected depends on the reason for the abort. For example, a three-engine RTLS is selected at the last moment, approximately 3 minutes, 34 seconds into the mission; whereas an RTLS chosen due to an engine out at liftoff is selected at the earliest time, approximately two minutes 20 seconds into the mission (after SOR separation).

After RTLS is selected, the vehicle continues downrange to dissipate excess main propulsion system propellant. The goal is to leave only enough main propulsion system propellant to be able to turn the vehicle around, fly back towards KSC and achieve the proper main engine cutoff conditions so the vehicle can glide to the KSC after external tank separation. During the downrange phase, a pitch-around maneuver is initiated (the time depends in part on the time of a main engine failure) to orient the orbiter/ external tank configuration to a heads up attitude, pointing toward the launch site. At this time, the vehicle is still moving away from the launch site, but the main engines are now thrusting to null the downrange velocity. In addition, excess orbital maneuvering system and reaction control system propellants are dumped by continuous orbital maneuvering system and reaction control system engine thrustings to improve the orbiter weight and center of gravity for the glide phase and landing.

The vehicle will reach the desired main engine cutoff point with less than 2 percent excess propellant remaining in the external tank. At main engine cutoff minus 20 seconds, a pitch-down maneuver (called powered pitch-down) takes the mated vehicle to the required external tank separation attitude and pitch rate. After main engine cutoff has been commanded, the external tank separation sequence begins, including a reaction control system translation that ensures that the orbiter does not recontact the external tank and that the orbiter has achieved the necessary pitch attitude to begin the glide phase of the RTLS.

After the reaction control system translation maneuver has been completed, the glide phase of the RTLS begins. From then on, the RTLS is handled similarly to a normal entry.

TRANSATLANTIC LANDING ABORT. The TAL abort mode was developed to improve the options available when a main engine fails after the last RTLS opportunity but before the first time that an AOA can be accomplished with only two main engines or when a major orbiter system failure, for example, a large cabin pressure leak or cooling system failure, occurs after the last RTLS opportunity, making it imperative to land as quickly as possible.



Transatlantic Landing Abort Option

In a TAL abort, the vehicle continues on a ballistic trajectory across the Atlantic Ocean to land at a predetermined runway. Landing occurs approximately 45 minutes after launch. The landing site is selected near the nominal ascent ground track of the orbiter in order to make the most efficient use of space shuttle main engine propellant. The landing site also must have the necessary runway length, weather conditions and U.S. State Department approval. Currently, the three landing sites that have been identified for a due east launch are Moron, Spain; Banjul, The Gambia; and Ben Guerir, Morocco.

To select the TAL abort mode, the crew must place the abort rotary switch in the TAL/AOA position and depress the abort push button before main engine cutoff. (Depressing it after main engine cutoff selects the AOA abort mode.) The TAL abort mode begins sending commands to steer the vehicle toward the plane of the landing site. It also rolls the vehicle heads up before main engine cutoff and sends commands to begin an orbital maneuvering system propellant dump (by burning the propellants through the orbital maneuvering system engines and the reaction control system engines). This dump is necessary to increase vehicle performance (by decreasing weight), to place the center of gravity in the proper place for vehicle control, and to decrease the vehicle's landing weight. TAL is handled like a nominal entry.

ABORT TO ORBIT. An ATO is an abort mode used to boost the orbiter to a safe orbital altitude when performance has been lost and it is impossible to reach the planned orbital altitude. If a Space Shuttle main engine fails in a region that results in a main engine cutoff under speed, the Mission Control Center will determine that an abort mode is necessary and will inform the crew. The orbital maneuvering system engines would be used to place the orbiter in a circular orbit.

ABORT ONCE AROUND. The AOA abort mode is used in cases in which vehicle performance has been lost to such an extent that either it is impossible to achieve a viable orbit or not enough Orbital Maneuvering System (OMS) propellant is available to accomplish the OMS thrusting maneuver to place the orbiter on orbit and the deorbit thrusting maneuver. In addition, an AOA is used in cases in which a major systems problem (cabin leak, loss of cooling) makes it necessary to land quickly. In the AOA abort mode, one OMS thrusting sequence is made to adjust the post-main engine cutoff orbit so a second orbital maneuvering system thrusting sequence will result in the vehicle deorbiting and landing at the AOA landing site (White Sands, N.M.; Edwards AFB; or KSC). Thus, an AOA results in the orbiter circling the Earth once and landing approximately 90 minutes after liftoff.

After the deorbit thrusting sequence has been executed, the flight crew flies to a landing at the planned site much as it would for a nominal entry.

CONTINGENCY ABORT. Contingency aborts are caused by loss of more than one main engine or failures in other systems. Loss of one main engine while another is stuck at a low thrust setting may also necessitate a contingency abort. Such an abort would maintain orbiter integrity for in-flight crew escape if a landing cannot be achieved at a suitable landing field.

Contingency aborts due to system failures other than those involving the main engines would normally result in an intact recovery of vehicle and crew. Loss of more than one main engine may, depending on engine failure times, result in a safe runway landing. However, in most three-engine-out cases during ascent, the orbiter would have to be ditched. The in-flight crew escape system would be used before ditching the orbiter.

ORBITER GROUND TURNAROUND

Spacecraft recovery operations at the nominal end-of-mission landing site are supported by approximately 160 Space Shuttle launch operations team members. Ground team members wearing self-contained atmospheric protective ensemble suits that protect them from toxic chemicals approach the spacecraft as soon as it stops rolling. The ground team members take sensor measurements to ensure the atmosphere in the vicinity of the spacecraft is not explosive. In the event of propellant leaks, a wind machine truck carrying a large fan will be moved into the area to create a turbulent airflow that will break up gas concentrations and reduce the potential for an explosion.

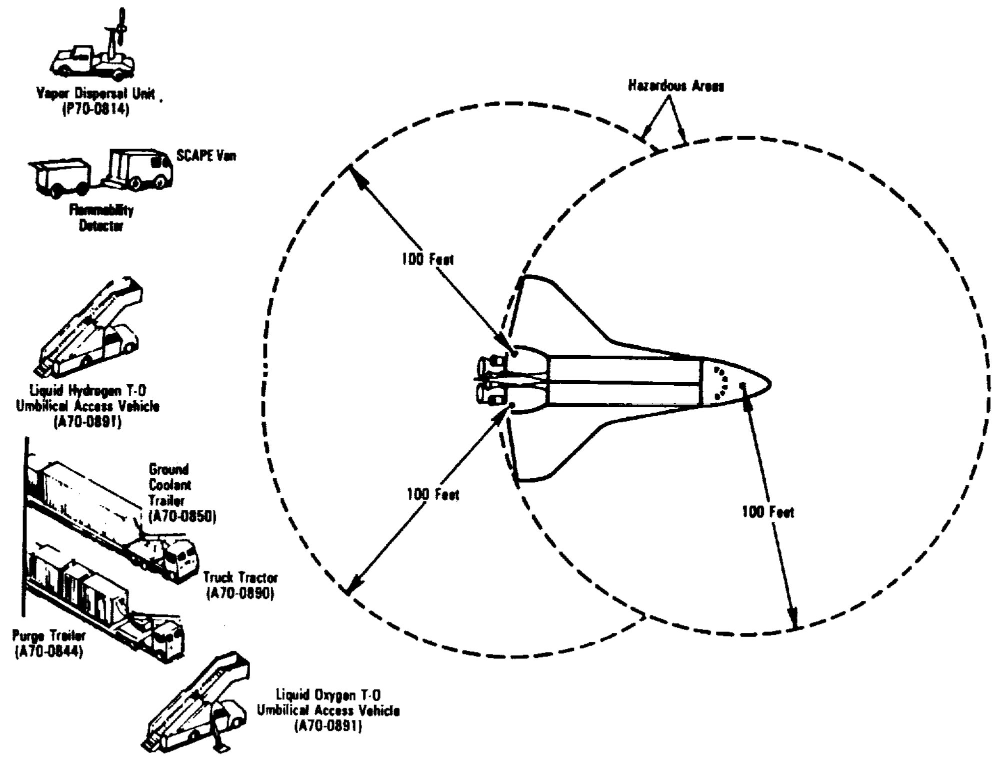
A ground support equipment air-conditioning purge unit is attached to the right-hand orbiter T-0 umbilical so cool air can be directed through the orbiter's aft fuselage, payload bay, forward fuselage, wings, vertical stabilizer, and orbital maneuvering system/reaction control system pods to dissipate the heat of entry.

A second ground support equipment ground cooling unit is connected to the left-hand orbiter T-0 umbilical spacecraft Freon Coolant loops to provide cooling for the flight crew and avionics during the postlanding and system checks. The spacecraft fuel cells remain powered up at this time. The flight crew will then exit the spacecraft, and a ground crew will power down the spacecraft.

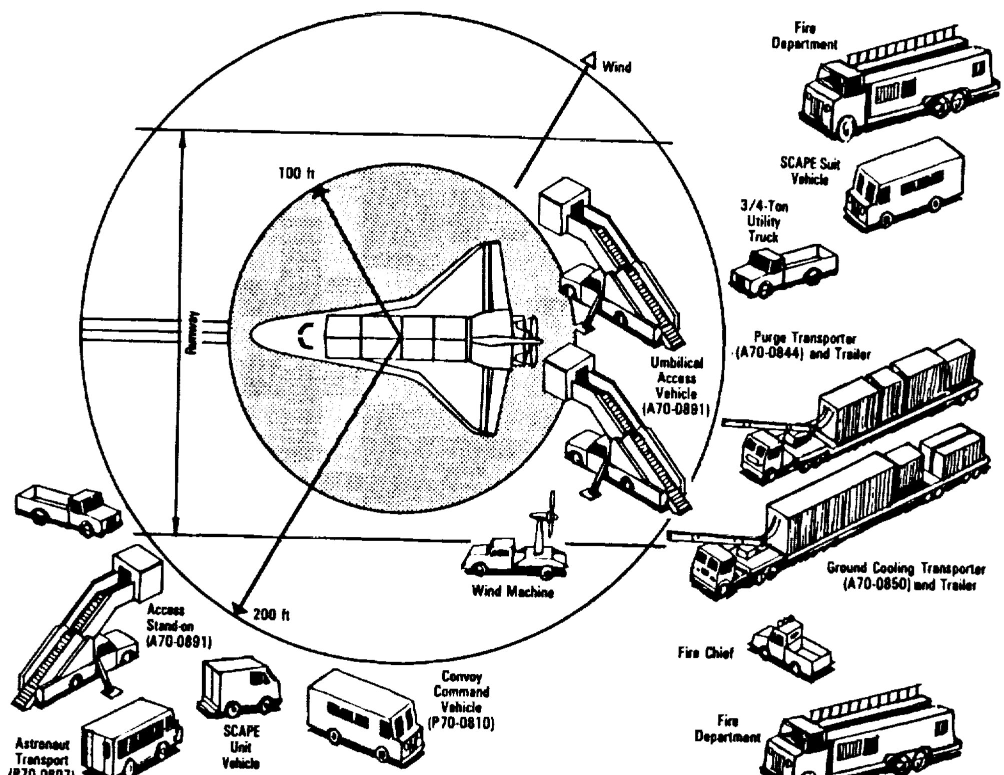
AT KSC, the orbiter and ground support equipment convoy move from the runway to the Orbiter Processing Facility.

If the spacecraft lands at Edwards, the same procedures and ground support equipment are used as at the KSC after the orbiter has stopped on the runway. The orbiter and ground support equipment convoy move from the runway to the orbiter mate and demate facility at Edwards. After detailed inspection, the spacecraft is prepared to be ferried atop the Shuttle carrier aircraft from Edwards to KSC. For ferrying, a tail cone is installed over the aft section of the orbiter.

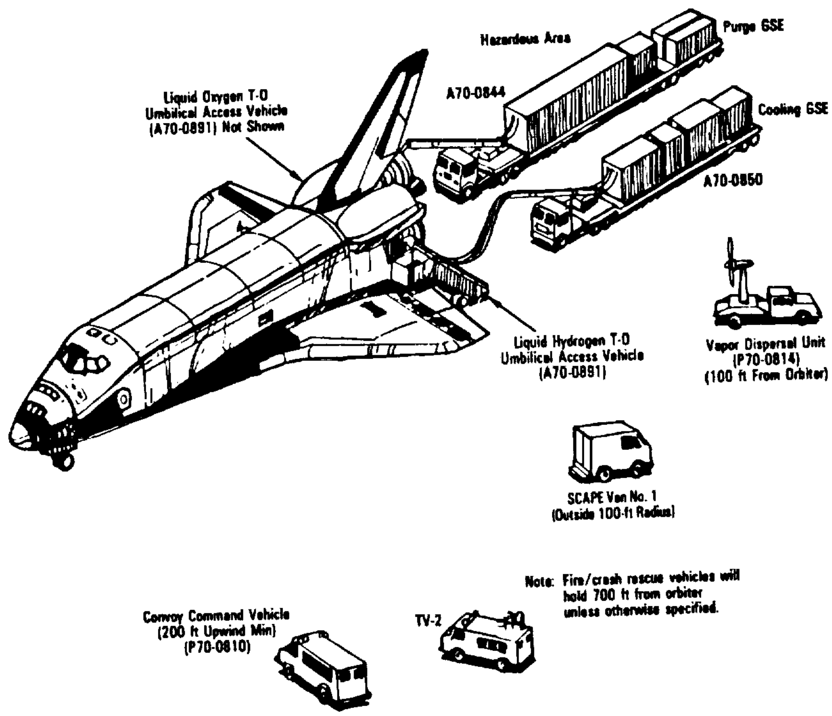
In the event of a landing at an alternate site, a crew of about eight team members will move to the landing site to assist the astronaut crew in preparing the orbiter for loading aboard the Shuttle carrier aircraft for transport back to the KSC. For landings outside the United States, personnel at the contingency landing sites will be provided



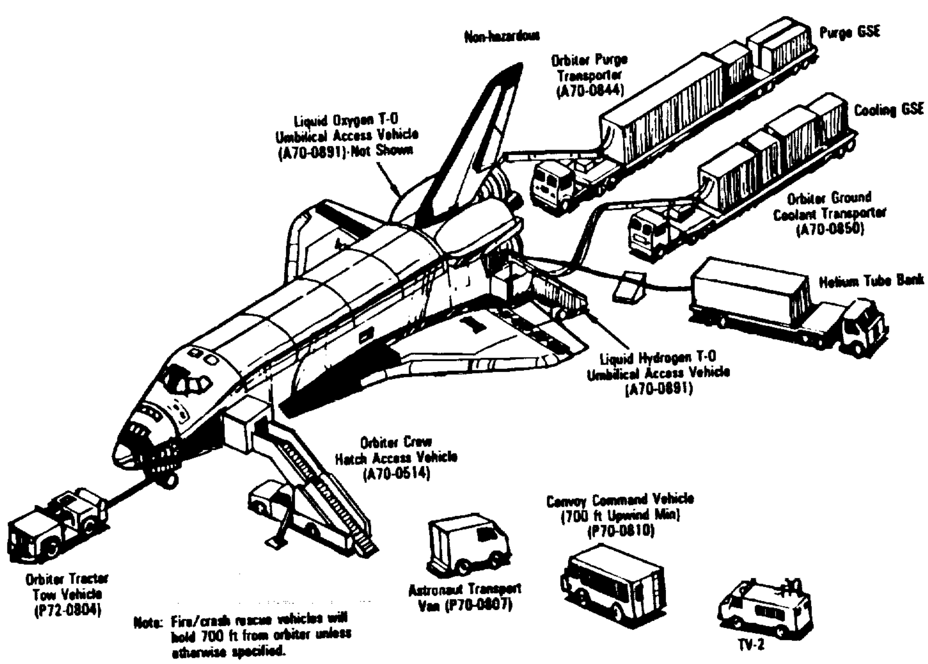
Orbiter Hazardous Areas at Landing and Convoy Positions



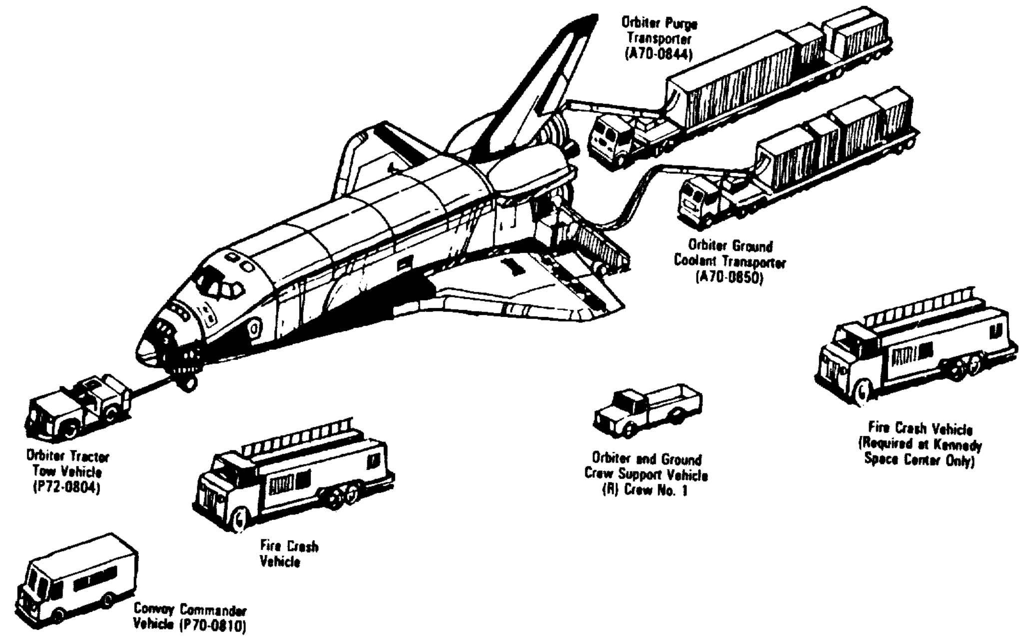
Orbiter Landing and Safing Preparations



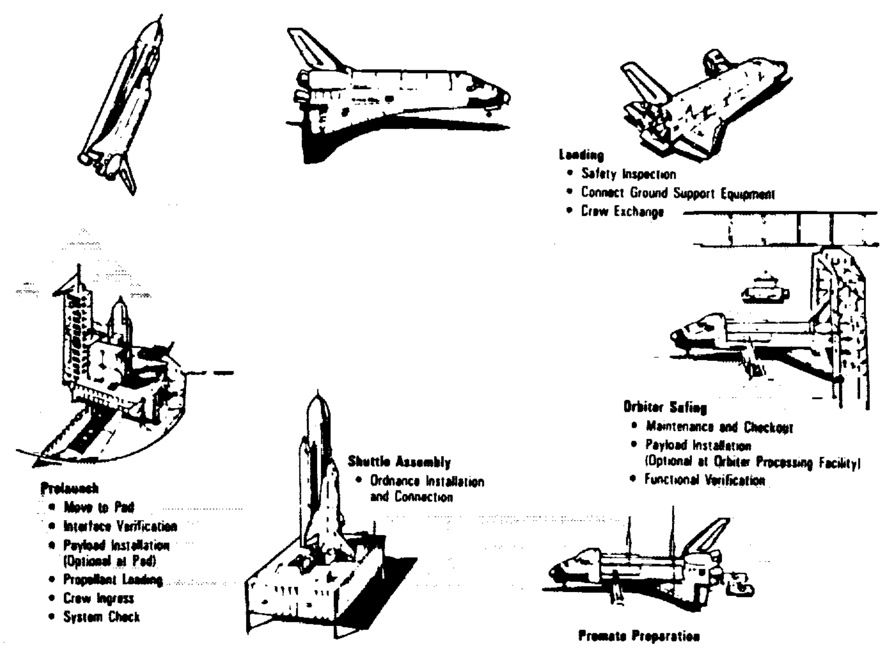
Orbiter Safing Operations



Orbiter Power-Down and Crew Egress



Typical Convoy tow Configuration



Kennedy Space Center Ground Turnaround Sequence minimum training on safe handling of the orbiter with emphasis on crash rescue training, how to tow the orbiter to a safe area, and prevention of propellant conflagration.

Upon its return to the Orbiter Processing Facility (OPF) at KSC, the orbiter is safed (ordnance devices safed), the payload (if any) is removed, and the orbiter payload bay is reconfigured from the previous mission for the next mission. Any required maintenance and inspections are also performed while the orbiter is in the OPF. A payload for the orbiter's next mission may be installed in the orbiter's payload bay in the OPF or may be installed in the payload bay when the orbiter is at the launch pad.

The spacecraft is then towed to the Vehicle Assembly Building and mated to the external tank. The external tank and solid rocket boosters are stacked and mated on the mobile launcher platform while the orbiter is being refurbished. Space Shuttle orbiter connections are made and the integrated vehicle is checked and ordnance is installed.

The mobile launcher platform moves the entire space shuttle system on four crawlers to the launch pad, where connections are made and servicing and checkout activities begin. If the payload was not installed in the OPF, it will be installed at the launch pad followed by prelaunch activities.

Space Shuttle launches from Vandenberg will use the Vandenberg Launch Facility (SL6), which was built but never used for the manned orbital laboratory program. This facility was modified for Space Transportation System use.

The runway at Vandenberg was strengthened and lengthened from 8,000 feet to 12,000 feet to accommodate the orbiter returning from space.

When the orbiter lands at Vandenberg, the same procedures and ground support equipment and convoy are used as at KSC after the orbiter stops on the runway. The orbiter and ground support equipment are moved from the runway to the Orbiter Maintenance and Checkout Facility at Vandenberg. The orbiter processing procedures used at this facility are similar to those used at the OPF at the KSC.

Space Shuttle buildup at Vandenberg differs from that of the KSC in that the vehicle is integrated on the launch pad. The orbiter is towed overland from the Orbiter Maintenance and Checkout Facility at Vandenberg to launch facility SL6.

SL6 includes the launch mount, access tower, mobile service tower, launch control tower, payload preparation room, payload changeout room, solid rocket booster refurbishment facility, solid rocket booster disassembly facility, and liquid hydrogen and liquid oxygen storage tank facilities.

The SRB start the on-the-launch-pad buildup followed by the external tank. The orbiter is then mated to the external tank on the launch pad.

The launch processing system at the launch pad is similar to the one used at KSC.

Kennedy Space Center Launch Operations has responsibility for all mating, prelaunch testing and launch control ground activities until the Space Shuttle vehicle clears the launch pad tower. Responsibility is then turned over to Mission Control Center-Houston. The Mission Control Center's responsibility includes ascent, on-orbit operations, entry, approach and landing until landing runout completion, at which time the orbiter is handed over to the postlanding operations at the landing site for turnaround and re-launch. At the launch site the SRBs and external tank are processed for launch and the SRBs are recycled for reuse.

OPERATIONAL IMPROVEMENTS AND MODIFICATIONS

Many of the changes and upgrades in the Space Shuttle systems and components were under way before the 51-L accident as part of NASA's continual improvement and upgrade program. However, NASA has taken advantage of the Space Shuttle program downtime since the accident to accelerate the testing and integration of these improvements and upgrades as well as fixes required as a result of the accident.

ORBITER. The following identifies the major improvements or modifications of the orbiter. Approximately 190 other modifications and improvements were also made.

ORBITAL MANEUVERING SYSTEM AND REACTION CONTROL SYSTEM AC-MOTOR-OPERATED VALVES. The 64 valves operated by AC-motors in the OMS and RCS were modified to incorporate a "sniff" line for each valve to permit monitoring of nitrogen tetroxide or monomethyl hydrazine in the electrical portion of the valves during ground operations. This new line reduces the probability of floating particles in the electrical microswitch portion of each valve, which could affect the operation of the microswitch position indicators for onboard displays and telemetry. It also reduces the probability of nitrogen tetroxide or monomethyl hydrazine leakage into the bellows of each ac-motor-operated valve.

PRIMARY REACTION CONTROL SYSTEM THRUSTERS. The wiring of the fuel and oxidizer injector solenoid valves was wrapped around each of the 38 primary RCS thrust chambers to remove electrical power from these valves in the event of a primary RCS thruster instability.

FUEL CELL POWER PLANTS. End-cell heaters on each fuel cell power plant were deleted because of potential electrical failures and replaced with Freon coolant loop passages to maintain uniform temperature throughout the power plants. In addition, the hydrogen pump and water separator of each fuel cell power plant were improved to minimize excessive hydrogen gas entrained in the power plant product water. A current measurement detector was added to monitor the hydrogen pump of each fuel cell power plant and provide an early indication of hydrogen pump overload.

The starting and sustaining heater system for each fuel cell power plant was modified to prevent overheating and loss of heater elements. A stack inlet temperature measurement was added to each fuel cell power plant for full visibility of thermal conditions.

The product water from all three fuel cell power plants flows to a single water relief control panel. The water can be directed from the single panel to the Environmental Control and Life Support System (ECLSS) potable water tank A or to the fuel cell power plant water relief nozzle. Normally, the water is directed to water tank A. In the event of a line rupture in the vicinity of the single water relief panel, water could spray on all three water relief panel lines causing them to freeze and preventing water discharge.

The product water lines from all three fuel cell power plants were modified to incorporate a parallel (redundant) path of product water to ECLSS potable water tank B in the event of a freeze-up in the single water relief panel. If the single water relief panel freezes up, pressure would build up and discharge through the redundant paths to water tank B.

A water purity sensor (pH) was added at the common product water outlet of the water relief panel to provide a redundant measurement of water purity (a single measurement of water purity in each fuel cell power plant was provided previously). If the fuel cell power plant pH sensor failed in the past, the flight crew had to sample the potable water.

AUXILIARY POWER UNITS. The APUs that have been in use to date have a limited life. Each unit was refurbished after 25 hours of operation because of cracks in the turbine housing, degradation of the gas generator catalyst (which varied up to approximately 30 hours of operation) and operation of the gas generator valve module (which also varied up to approximately 30 hours of operation). The remaining parts of the APU were qualified for 40 hours of operation.

Improved APUs are scheduled for delivery in late 1988. A new turbine housing increases the life of the housing to 75 hours of operation (50 missions); a new gas generator increases its life to 75 hours; a new standoff design of the gas generator valve module and fuel pump deletes the requirement for a water spray system that was required previously for each APU upon shutdown after the first OMS thrusting period or orbital checkout; and the addition of a third seal in the middle of the two existing seals for the shaft of the fuel pump/lube oil system (previously only two seals were located on the shaft, one on the fuel pump side and one on the gearbox lube oil side) reduces the probability of hydrazine leaking into the lube oil system.

The deletion of the water spray system for the gas generator valve module and fuel pump for each APU results in a weight reduction of approximately 150 pounds for each orbiter. Upon the delivery of the improved units, the life-limited APUs will be refurbished to the upgraded design.

In the even that a fuel tank valve switch in an auxiliary power unit is inadvertently left on or an electrical short occurs within the valve electrical coil, additional protection is provided to prevent overheating of the fuel isolation valves.

MAIN LANDING GEAR. The following modifications were made to improve the performance of the main landing gear elements:

- The thickness of the main landing gear axle was increased to provide a stiffer configuration that reduces brake-to-axle deflections and precludes brake damage experienced in previous landings. The thicker axle should also minimize tire wear.

- Orifices were added to hydraulic passages in the brake's piston housing to prevent pressure surges and brake damage caused by a wobble/pump effect.

- The electronic brake control boxes were modified to balance hydraulic pressure between adjacent brakes and equalize energy applications. The anti-skid circuitry previously used to reduce brake pressure to the opposite wheel if a flat tire was detected has now been removed.

- The carbon-lined beryllium stator discs in each main landing gear brake were replaced with thicker discs to increase braking energy significantly.

- A long-term structural carbon brake program is in progress to replace the carbon-lined beryllium stator discs with a carbon configuration that provides higher braking capacity by increasing maximum energy absorption.

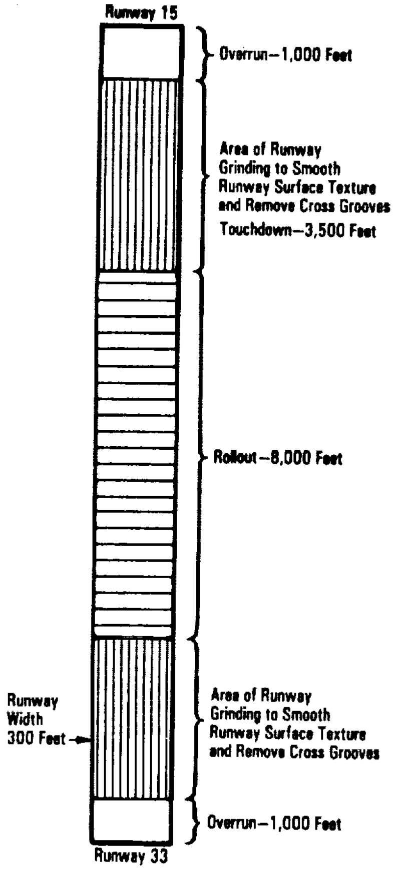
- Strain gauges were added to each nose and main landing gear wheel to monitor tire pressure before launch, deorbit and landing.

Other studies involve arresting barriers at the end of landing site runways (except lakebed runways), installing a skid on the landing gear that could preclude the potential for a second blown tire on the same gear after the first tire has blown, providing "roll on rim" for a predictable roll if both tires are lost on a single or multiple gear and adding a drag chute.

Studies of landing gear tire improvements are being conducted to determine how best to decrease tire wear observed after previous KSC landings and how to improve crosswind landing capability.

Modifications were made to the KSC Shuttle Landing Facility runway. The full 300-foot width of 3,500-foot sections at both ends of the runway were ground to smooth the runway surface texture and remove cross grooves. The modified corduroy ridges are smaller than those they replaced and run the length of the runway rather than across its width. The existing landing zone light fixtures were also modified, and the markings of the entire runway and overruns were repainted. The primary purpose of the modifications is to enhance safety by reducing tire wear during landing.

NOSE WHEEL STEERING. The nose wheel steering system was modified on Columbia (OV-102) for the 61-C mission, and Discovery (OV-103) and Atlantis (OV-104) are being similarly modified before their return to flight. The modification allows a safe high-speed engagement of the nose wheel steering system and provides positive lateral directional control of the orbiter during rollout in the presence of high crosswinds and blown tires.



Shuttle Landing Facility Runway Modifications at Kennedy Space Center

THERMAL PROTECTION SYSTEM. The area aft of the reinforced carbon-carbon nose cap to the nose landing gear doors has sustained damage (tile slumping) during flight operations from impact during ascent and overheating during reentry. This area, which previously was covered with high-temperature reusable surface insulation tiles, will now be covered with reinforced carbon-carbon.

The low-temperature thermal protection system tiles on Columbia's midbody, payload bay doors and vertical tail were replaced with advanced Flexible Reusable Surface iInsulation (FRSI) blankets.

Because of evidence of plasma flow on the lower wing trailing edge and elevon landing edge tiles (wing/elevon cove) at the outboard elevon tip and inboard elevon, the low-temperature tiles are being replaced with Fibrous Refractory Composite Insulation (FRC1-12) and High-Temperature (HRSI-22) tiles along with gap fillers on Discovery and Atlantis. On Columbia only gap fillers are installed in this area.

WING MODIFICATION. Before the wings for Discovery and Atlantis were manufactured, a weight reduction program was instituted that resulted in a redesign of certain areas of the wing structure. An assessment of wing air loads from actual flight data indicated greater loads on the wing structure than predicted. To maintain positive margins of safety during ascent, structural modifications were incorporated into certain areas of the wings.

MID-FUSELAGE MODIFICATIONS. Because of additional detailed analysis of actual flight data concerning descent-stress thermal-gradient loads, torsional straps were added to tie all the lower mid-fuselage stringers in bays 1 through 11 together in a manner similar to a box section. This eliminates rotational (torsional) capabilities to provide positive margins of safety.

Also, because of the detailed analysis of actual descent flight data, room-temperature vulcanizing silicone rubber material was bonded to the lower mid-fuselage from bays 4 through 11 to act as a heat sink, distributing temperatures evenly across the bottom of the mid-fuselage, reducing thermal gradients and ensuring positive margins of safety.

GENERAL PURPOSE COMPUTERS. New upgraded General Purpose Computers (GPC), IBM AP-101S, will replace the existing GPCs aboard the Space Shuttle orbiters in late 1988 or early 1989. The upgraded computers allow NASA to incorporate more capabilities into the orbiters and apply advanced computer technologies that were not available when the orbiter was first designed. The new computer design began in January 1984, whereas the older design began in January 1972. The upgraded GPCs provide two-and-a-half times the existing memory capacity and up to three times the existing processor speed with minimum impact on flight software. They are half the size, weigh approximately half as much, and require less power to operate.

INERTIAL MEASUREMENT UNITS. The new High-Accuracy Inertial Navigation System (HAINS) will be phased in in 1988-89 to augment the present KT-70 inertial measurement units . These new Inertial Measurement Units (IMUs) will result in lower program costs over the next decade, ongoing production support, improved performance, lower failure rates and reduced size and weight. The HAINS IMUs also contain an internal dedicated microprocessor with memory for processing and storing compensation and scale factor data from the IMU manufacturer's calibration, thereby reducing the need for extensive initial load data for the orbiter's computers. The HAINS is both physically and functionally interchangeable with the KT-70 IMU.

CREW ESCAPE SYSTEM. The in-flight crew escape system is provided for use only when the orbiter is in controlled gliding flight and unable to reach a runway. This would normally lead to ditching. The crew escape system provides the flight crew with an alternative to water ditching or to landing on terrain other than a landing site. The probability of the flight crew surviving a ditching is very small.

The hardware changes required to the orbiters would enable the flight crew to equalize the pressurized crew compartment with the outside pressure via a depressurization valve opened by pyrotechnics in the crew compartment aft bulkhead that would be manually activated by a flight crew member in the middeck of the crew compartment; pyrotechnically jettison the crew ingress/ egress side hatch in the middeck of the crew compartment; and bail out from the middeck of the orbiter through the ingress/ egress side hatch opening after manually deploying the escape pole through, outside and down from the side hatch opening. One by one, each crew member attaches a lanyard hook assembly, which surrounds the deployed escape pole, to his parachute harness and egresses through the side hatch opening. Attached to the escape pole, the crew member slides down the pole and off the end. The escape pole provides a trajectory that takes the crew members below the orbiter's left wing.

Changes were also made in the software of the orbiter's general purpose computers. The software changes were required for the primary avionics software system and the backup flight system for transatlantic-landing and glide-return-to-launch-site aborts. The changes provide the orbiter with an automatic-mode input by the flight crew through keyboards on the commander's and/or pilot's panel C3, which provides the orbiter with an automatic stable flight for crew bailout.

The side hatch jettison feature also could be used in a landing emergency.

EMERGENCY EGRESS SLIDE. The emergency egress slide provides orbiter flight crew members with a means for rapid and safe exit through the orbiter middeck ingress/egress side hatch after a normal opening of the side hatch or after jettisoning the side hatch at the nominal end-of-mission landing site or at a remote or emergency landing site.

The emergency egress slide replaces the emergency egress side hatch bar, which required the flight crew members to drop approximately 10.5 feet to the ground. The previous arrangement could have injured crew members or prevented an already-injured crew member from evacuating and moving a safe distance from the orbiter.

17-INCH ORBITER/EXTERNAL TANK DISCONNECTS. Each mated pair of 17-inch disconnects contains two flapper valves: one on the orbiter side and one on the external tank side. Both valves in each disconnect pair are opened to permit propellant flow between the orbiter and the external tank. Prior to separation from the external tank, both valves in each mated pair of disconnects are commanded closed by pneumatic (helium) pressure from the main propulsion system. The closure of both valves in each disconnect pair prevents propellant discharge from the external tank or orbiter at external tank separation. Valve closure on the orbiter side of each disconnect also prevents contamination of the orbiter main propulsion system during landing and ground operations.

Inadvertent closure of either valve in a 17-inch disconnect during main engine thrusting would stop propellant flow from the external tank to all three main engines. Catastrophic failure of the main engines and external tank feed lines would result.

To prevent inadvertent closure of the 17-inch disconnect valves during the Space Shuttle main engine thrusting period, a latch mechanism was added in each orbiter half of the disconnect. The latch mechanism provides a mechanical backup to the normal fluid-induced-open forces. The latch is mounted on a shaft in the flowstream so that it overlaps both flappers and obstructs closure for any reason.

In preparation for external tank separation, both valves in each 17-inch disconnect are commanded closed. Pneumatic pressure from the main propulsion system causes the latch actuator to rotate the shaft in each orbiter 17-inch disconnect 90 degrees, thus freeing the flapper valves to close as required for external tank separation.

A backup mechanical separation capability is provided in case a latch pneumatic actuator malfunctions. When the orbiter umbilical initially moves away from the ET umbilical, the mechanical latch disengages from the ET flapper valve and permits the orbiter disconnect flapper to toggle the latch. This action permits both flappers to close.

SPACE SHUTTLE MAIN ENGINE MARGIN IMPROVEMENT PROGRAM

Improvements to the Space Shuttle Main Engines (SSMEs) for increased margin and durability began with a formal Phase II program in 1983. Phase II focused on turbo-machinery to extend the time between high-pressure turbopump overhauls by reducing the operating temperature in the high-pressure fuel turbopump and by incorporating margin improvements to the High Pressure Fuel Turbopump (HPFT) rotor dynamics (whirl), turbine blade and HPFT bearings. Phase II certification was completed in 1985, and all the changes have been incorporated into the SSMEs for the STS-26 mission.

In addition to the Phase II improvements, additional changes in the SSME have been incorporated to further extend the engines' margin and durability. The main changes were to the high-pressure turbo-machinery, main combustion chamber, hydraulic actuators and high-pressure turbine discharge temperature sensors. Changes were also made in the controller software to improve engine control.

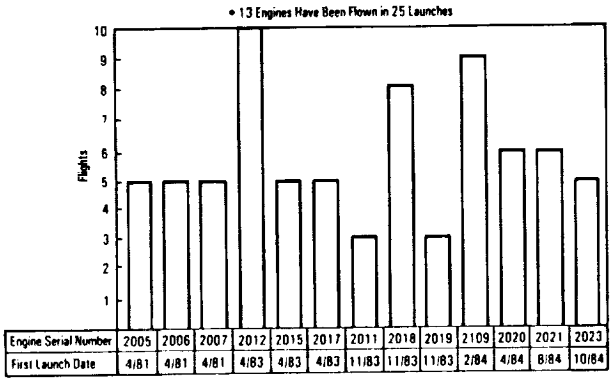
Minor high-pressure turbo-machinery design changes resulted in margin improvements to the turbine blades, thereby extending the operating life of the turbopumps. These changes included applying surface texture to important parts of the fuel turbine blades to improve the material properties in the pressure of hydrogen and incorporating a damper into the high-pressure oxidizer turbine blades to reduce vibration.

Main combustion chamber life has been increased by plating a welded outlet manifold with nickel. Margin improvements have also been made to five hydraulic actuators to preclude a loss in redundancy on the launch pad. Improvements in quality have been incorporated into the servo-component coil design along with modifications to increase margin. To address a temperature sensor in-flight anomaly, the sensor has been redesigned and extensively tested without problems.

To certify the improvements to the SSMEs and demonstrate their reliability through margin (or limit testing), an aggressive ground test program was initiated in December 1986. From December 1986 to December 1987, 151 tests and 52.363 seconds of operation (equivalent to 100 Shuttle missions) were performed. The SSMEs have exceeded 300,000 seconds total test time, the equivalent of 615 Space Shuttle missions. These hot-fire ground tests are performed at the single-engine test stands NASA's Stennis Space Center in Mississippi and at Rockwell International's Rocketdyne Division's Santa Susana Field Laboratory in California.

SSME FLIGHT PROGRAM

By January 1986, there have been 25 flights (75 engine launches with three SSMEs per flight) of the SSMEs. A total of 13 engines were flown, and SSME reusability was demonstrated. One engine (serial number 2012) has been flown 10 times; 10 other engines have flown between five and nine times. Two off-nominal conditions were experienced on the launch pad and one during flight. Two fail-safe shutdowns occurred on the launch pad during engine start but before SRB ignition. In each case, the controller detected a loss of redundancy in the hydraulic actuator system and commanded engine shutdown in keeping with the launch commit criteria. Another loss of redundancy occurred in flight with a loss of a red-line temperature sensor and its backup. The engine was commanded to shut down, but the other two engines safely delivered the Space Shuttle to orbit. A major upgrade of these components was implemented to prevent a recurrence of these conditions and will be incorporated for STS-26.



SSME Flight Experience Demonstrates Reliability (Through February 1, 1986)

SOLID ROCKET MOTOR REDESIGN

On June 13, 1986, President Reagan directed NASA to implement, as soon as possible, the recommendations of the "Presidential Commission on the Space Shuttle Challenger Accident." NASA developed a plan to provide a Redesigned Solid Rocket Motor (RSRM). The primary objective of the redesign effort was to provide an SRM that is safe to fly. A secondary objective was to minimize impact on the schedule by using existing hardware, to the extent practical, without compromising safety. A joint redesign team was established that included participation from Marshall Space Flight Center, Morton Thiokol and other NASA centers as well as individuals from outside NASA.

An "SRM Redesign Project Plan" was developed to formalize the methodology for SRM redesign and requalification. The plan provided an overview of the organizational responsibilities and relationships, the design objectives, criteria and process; the verification approach and process; and a master schedule. The companion "Development and Verification Plan" defined the test program and analyses required to verify the redesign and the unchanged components of the SRM.

All aspects of the existing SRM were assessed, and design changes were required in the field joint, case-to-nozzle joint, nozzle, factory joint, propellant grain shape, ignition system and ground support equipment. No changes were made in the propellant, liner or castable inhibitor formulations. Design criteria were established for each component to ensure a safe design with an adequate margin of safety. These criteria focused on loads, environments, performance, redundancy, margins of safety and verification philosophy.

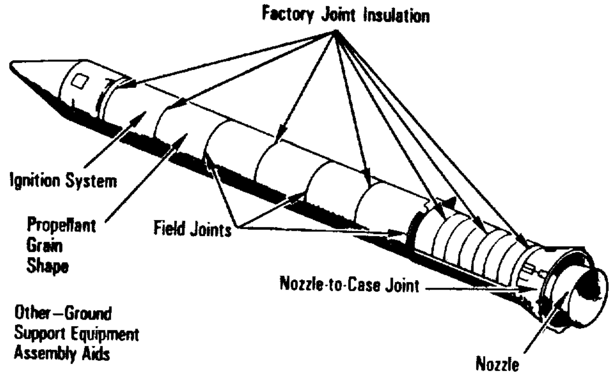
The criteria were converted into specific design requirements during the Preliminary Requirements Reviews held in July and August 1986. The design developed from these requirements was assessed at the Preliminary Design Review held in September 1986 and baselined in October 1986. The final design was approved at the Critical Design Review held in October 1987. Manufacture of the RSRM test hardware and the first flight hardware began prior to the Preliminary Design Review (PDR) and continued in parallel with the hardware certification program. The Design Certification Review will review the analyses and test results versus the program and design requirements to certify the redesigned SRM is ready to fly.

ORIGINAL VERSUS REDESIGNED SRM FIELD JOINT. The SRM field-joint metal parts, internal case insulation and seals were redesigned and a weather protection system was added.

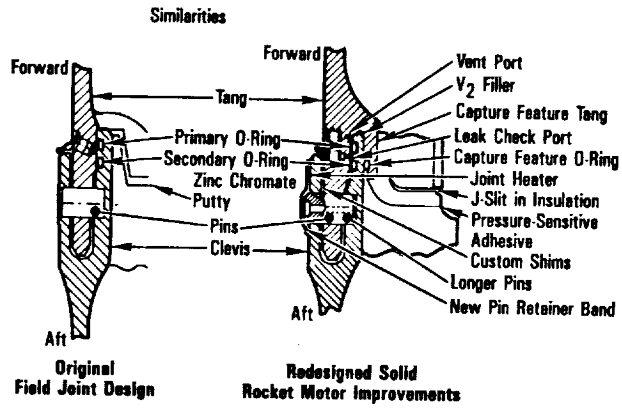
In the STS 51-L design, the application of actuating pressure to the upstream face of the O-ring was essential for proper joint sealing performance because large sealing gaps were created by pressure-induced deflections, compounded by significantly reduced O-ring sealing performance at low temperature. The major change in the motor case is the new tang capture feature to provide a positive metal-to-metal interference fit around the circumference of the tang and clevis ends of the mating segments. The interference fit limits the deflection between the tang and clevis O-ring sealing surfaces caused by motor pressure and structural loads. The joints are designed so that the seals will not leak under twice the expected structural deflection and rate.

The new design, with the tang capture feature, the interference fit and the use of custom shims between the outer surface of the tang and inner surface of the outer clevis leg, controls the O-ring sealing gap dimension. The sealing gap and the O-ring seals are designed so that a positive

ORIGINAL VERSUS REDESIGNED SRM FIELD JOINT



Solid Rocket Booster Redesign and Reassessment



Field Joint Comparison

compression (squeeze) is always on the O-rings. The minimum and maximum squeeze requirements include the effects of temperature, O-ring resiliency and compression set, and pressure. The clevis O-ring groove dimension has been increased so that the O-ring never fills more than 90 percent of the O-ring groove and pressure actuation is enhanced.

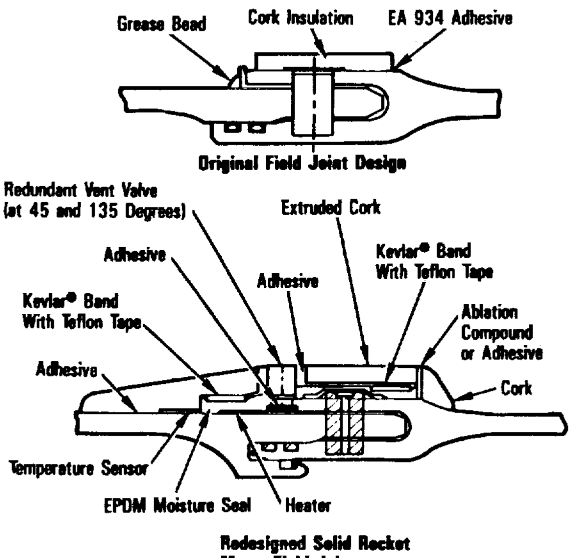
The new field joint design also includes a new O-ring in the capture feature and an additional leak check port to ensure that the primary O-ring is positioned in the proper sealing direction at ignition. This new or third O-ring also serves as a thermal barrier in case the sealed insulation is breached.

The field joint internal case insulation was modified to be sealed with a pressure-actuated flap called a J-seal, rather than with putty as in the STS 51-L configuration.

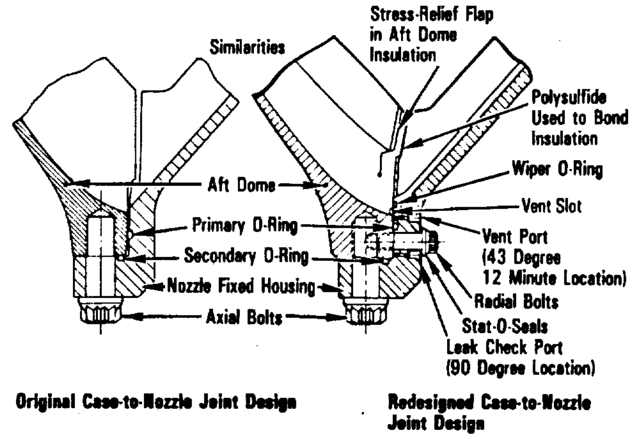
Longer field-joint-case mating pins, with a reconfigured retainer band, were added to improve the shear strength of the pins and increase the metal parts' joint margin of safety. The joint safety margins, both thermal and structural, are being demonstrated over the full ranges of ambient temperature, storage compression, grease effect, assembly stresses and other environments. External heaters with integral weather seals were incorporated to maintain the joint and O-ring temperature at a minimum of 75 F. The weather seal also prevents water intrusion into the joint.

ORIGINAL VERSUS REDESIGNED SRM CASE-TO-NOZZLE JOINT. The SRM case-to nozzle joint, which experienced several instances of O-ring erosion in flight, has been redesigned to satisfy the same requirements imposed upon the case field joint. Similar to the field joint, cast-to-nozzle joint modifications have been made in the metal parts, internal insulation and O-rings. Radial bolts with Stato-O-Seals were added to minimize the joint sealing gap opening. The internal insulation was modified to be sealed adhesively, and third O-ring was included. The third O-ring serves as a dam or wiper in front of the primary O-ring to prevent the polysulfide adhesive from being extruded into the primary O-ring groove. It also serves as a thermal barrier in case the polysulfide adhesive is breached. The polysulfide adhesive replaces the putty used in the 51-L joint. Also, an additional leak check port was added to reduce the amount of trapped air in the joint during the nozzle installation process and to aid in the leak check procedure.

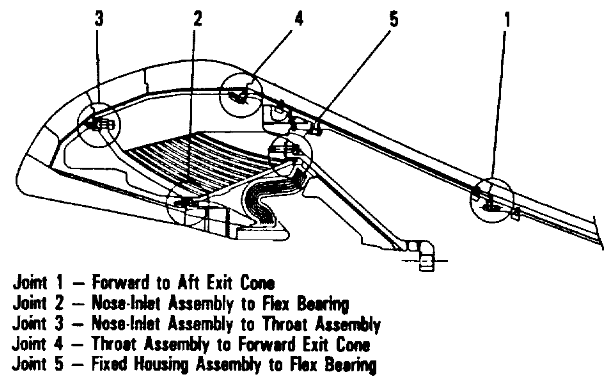
NOZZLE. The internal joints of the nozzle metal parts have been redesigned to incorporate redundant and verifiable O-rings at each joint. The nozzle steel fixed housing part has been redesigned to permit the incorporation of the 100 radial bolts that attach the fixed housing to the case's aft dome. Improved bonding techniques are being used for the nozzle nose inlet, cowl/boot and aft exit cone assemblies. The distortion of the nose inlet assembly's metal-part-to-ablative-parts bond line has been eliminated by increasing the thickness of the aluminum nose inlet housing and improving the bonding process. The tape-wrap angle of the carbon cloth fabric in the areas of the nose inlet and throat assembly parts was changed to improve the ablative insulation erosion tolerance. Some of these ply-angle changes were in progress prior to STS 51-L. The cowl and outer boot ring has additional structural support with increased thickness and contour changes to increase their margins of safety. Additionally, the outer boot ring ply configuration was altered.



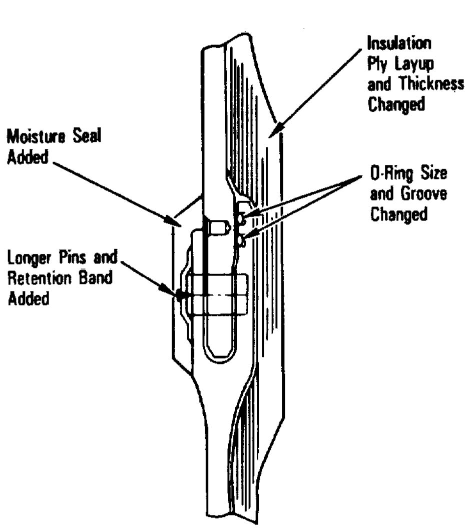
Field Joint Protection System



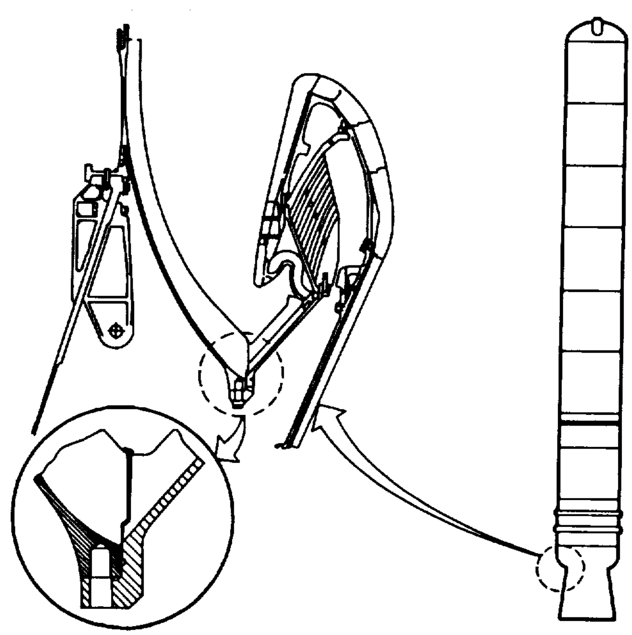
Case-to-Nozzle Joint Design



Redesigned Solid Rocket Motor Nozzle Internal Seals



Redesigned Factory Joint



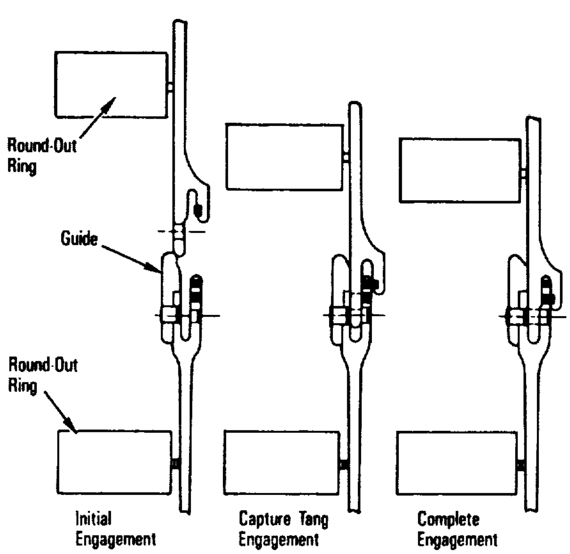
Nozzle-to-Case Joint

FACTORY JOINT. Minor modifications were made in the case factory joints by increasing the insulation thickness and lay-up to increase the margin of safety on the internal insulation. Longer pins were also added, along wit a reconfigured retainer band and new weather seal to improve factory joint performance and increase the margin of safety. Additionally, the O-ring and O-ring groove size was changed to be consistent with the field joint.

PROPELLANT. The motor propellant forward transition region was recontoured to reduce the stress fields between the star and cylindrical portions of the propellant grain.

IGNITION SYSTEM. Several minor modifications were incorporated into the ignition system. The aft end of the igniter steel case, which contains the igniter nozzle insert, was thickened to eliminate a localized weakness. The igniter internal case insulation was tapered to improve the manufacturing process. Finally, although vacuum putty is still being used at the joint of the igniter and case forward dome, it was changed to eliminate asbestos as one of its constituents.

GROUND SUPPORT EQUIPMENT. The ground support equipment has been redesigned to (1) minimize the case distortion during handling at the launch site; (2) improve the segment tang and clevis joint measurement system for more accurate reading of case diameters to facilitate stacking; (3) minimize the risk of O-ring damage during joint mating; and (4) improve leak testing of the igniter, case and nozzle field joints. A Ground Support Equipment (GSE) assembly aid guides the segment tang into the clevis and rounds the two parts with each other. Other GSE modifications include transportation monitoring equipment and lifting beam.



Ground Support Equipment Assembly Aids

DESIGN ANALYSIS SUMMARY. Improved, state-of-the-art, analyses related to structural strength, loads, stress, dynamics, fracture mechanics, gas and thermal dynamics, and material characterization and behavior were performed to aid the field joint, nozzle-to-case joint and other designs. Continuing these analyses will ensure that the design integrity and system compatibility adhere to design requirements and operational use. These analyses will be verified by tests, whose results will be correlated with pretest predictions.

VERIFICATION/CERTIFICATION TEST. The verification program demonstrates that the RSRM meets all design and performance requirements, and that failure modes and hazards have been eliminated or controlled. The verification program encompasses the following program phases: development, certification, acceptance, preflight checkout, flight and postflight.

Redesigned SRM certification is based on formally documented results of development motor tests; qualification motor tests and other tests and analyses. The certification tests are conducted under strict control of environments, including thermal and structural loads; assembly, inspection and test procedures; and safety, reliability, maintainability and quality assurance surveillance to verify that flight hardware meets the specified performance and design requirements. The "Development and Verification Plan" stipulates the test program, which follows a rigorous sequence wherein successive tests build on the results of previous tests leading to formal

The test activities include laboratory and component tests, subscale tests, full-scale simulation and full-scale motor static test firings. Laboratory and component tests are used to determine component properties and characteristics. Subscale motor firings are used to simulate gas dynamics and thermal conditions for components and subsystem design. Full-scale hardware simulators are used to verify analytical models; determine hardware assembly characteristics; determine joint deflection characteristics; determine joint performance under short-duration hot-gas tests, including joint flaws and flight loads; and determine redesigned hardware structural characteristics.

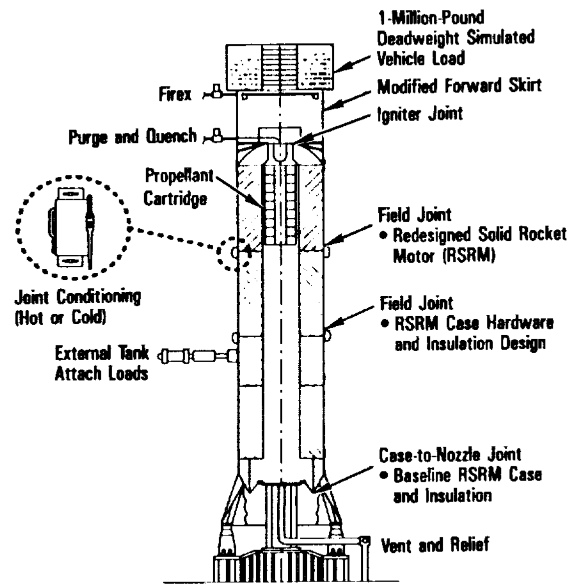
Fourteen full-scale joint assembly demonstration vertical mate/demate tests, with eight interspersed hydro tests to simulate flight hardware refurbishment procedures, were completed early for the redesigned capture-feature hardware. Assembly loads were as expected, and the case growth was as predicted with no measurable increase after three hydro-proof tests.

Flight-configuration aft and center segments were fabricated, loaded with live propellant, and used for assembly test article stacking demonstration tests at Kennedy Space Center. These tests were pathfinder demonstrations for the assembly of flight hardware using newly developed ground support equipment.

In a long-term stack test, a full-scale casting segment, with live propellant, has been mated vertically with a J-seal insulation segment and is undergoing temperature cycling. This will determine the compression set of the J-seal, aging effects and long-term propellant slumping effects.

The Structural Test Article (STA-3), consisting of flight-type forward and aft motor segments and forward and aft skirts, was subjected to extensive static and dynamic structural testing, including maximum prelaunch, liftoff and flight (maximum dynamic pressure) structural loads.

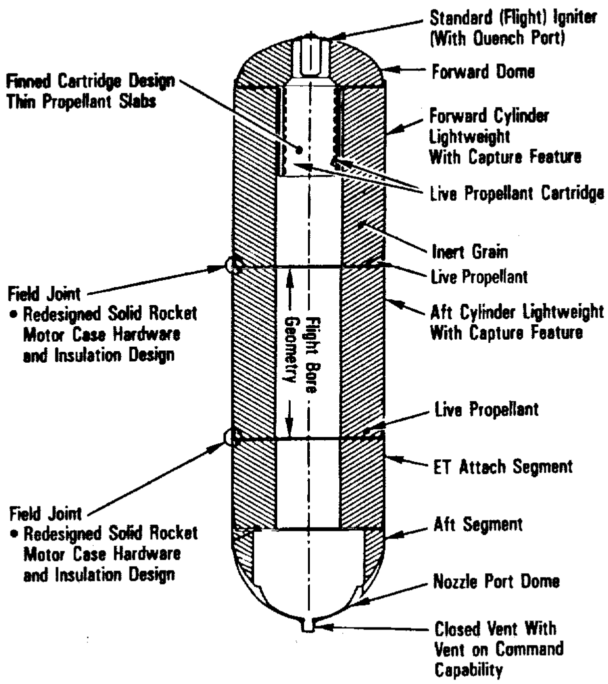
Redesigned SRM certification includes testing the actual flight configuration over the full range of operating environments and conditions. The joint environment simulator, transient pressure test article, and the nozzle joint environment simulator test programs all utilize full-scale flight design hardware and subject the RSRM design features to the maximum expected operating pressure, maximum pressure rise rate and temperature extremes during ignition tests. Additionally, the Transient Pressure Test Article (TPTA) is subjected to ignition and liftoff loads as well as maximum dynamic pressure structural loads.



Transient Pressure Test Article Configuration

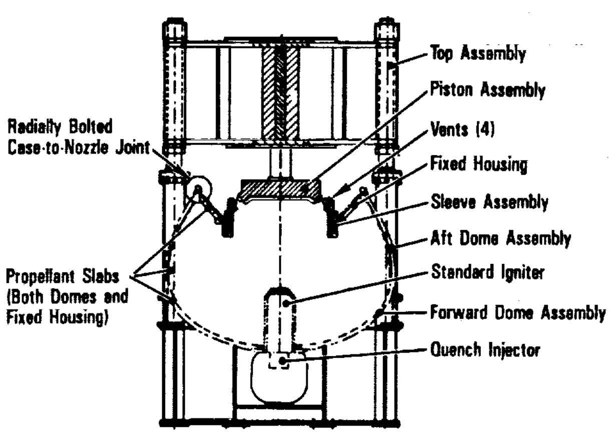
Four TPTA tests have been completed to subject the redesigned case field and case-to-nozzle joints to the above-described conditions. The field and case-to-nozzle joints were temperature-conditioned to 75 F. and contained various types of flaws in the joints so that the primary and secondary O-rings could be pressure-actuated, joint rotation and O-ring performance could be evaluated and the redesigned joints could be demonstrated as fail safe.

Six of the seven Joint Environment Simulators (JES) tests have been completed. The JES test program initially used the STS 51-L configuration hardware to evaluate the joint performance with prefabricated blowholes through the putty. The JES-1 test series, which consisted of two tests, established a structural and performance data base for the STS 51-L configuration with and without a replicated joint failure. The JES-2 series, two tests, also used the STS 51-L case metal-part joint but with a bonded labyrinth and U-seal insulation that was an early design variation of the J-seal. Tests were conducted with and without flaws built into the U-seal joint insulation; neither joint showed O-ring erosion or blow-by. The JES-3 series, three tests, uses almost exact flight configuration hardware, case field-joint capture feature with interference fit and J-seal insulation.



Joint Environment Simulation Configuration

Four of five nozzle JES tests have been successfully conducted. The STS 51-L hardware configuration hydro test confirmed predicted case-to-nozzle-joint deflection. The other three tests used the radially bolted RSRM configuration.



Nozzle Joint Environment Simulator Configuration

Seven full-scale, full-duration motor static tests are being conducted to verify the integrated RSRM performance. These include one engineering test motor used to (1) provide a data base for STS 51-L-type field joints; (2) evaluate new seal material; (3) evaluate the ply-angle change in the nozzle parts,; (4) evaluate the effectiveness of graphite composite stiffener rings to reduce joint rotation; and (5) evaluate field-joint heaters. There were two development motor tests and three qualification motor tests for final flight configuration and performance certification. There will be one flight Production Verification Motor that contains intentionally induced defects in the joints to demonstrate joint performance under extreme worse case conditions. The QM-7 and QM-8 motors were subjected to liftoff and maximum dynamic pressure structural loads, QM-7 was temperature-conditioned to 90 F., and QM-8 was temperature-conditioned to 40 F.

An assessment was conducted to determine the full-duration static firing test attitude necessary to certify the design changes completely. The assessment included establishing test objectives, defining and quantifying attitude-sensitive parameters, and evaluating attitude options. Both horizontal and vertical (nozzle up and down) test attitudes were assessed. In all three options, consideration was given to testing with and without externally applied loads. This assessment determined that the conditions influencing the joint and insulation behavior could best be tested to design extremes in the horizontal attitude. In conjunction with the horizontal attitude for the RSRM full-scale testing, it was decided to incorporate externally applied loads. A second horizontal test stand for certification of the RSRM was constructed at Morton Thiokol. This new stand, designated as the T-97 Large Motor Static Test Facility, is being used to simulate environmental stresses, loads and temperatures experienced during an actual Shuttle launch and ascent. The new test stand also provides redundancy for the existing stand.

NON-DESTRUCTIVE EVALUATION. The Shuttle 51-L and Titan 34D-9 vehicle failures, both of which occurred in 1986, resulted in major reassessments of each vehicle's design, processing, inspection and operations. While the Shuttle SRM insulation/ propellant integrity was not implicated in the 51-L failure, the intent is to preclude a failure similar to that experienced by Titan. The RSRM field joint is quite tolerant of unbonded insulation. It has sealed insulation to prevent hot combustion products from reaching the insulation-to-case bond line. The bonding processes have been improved to reduce contamination potential, and the new geometry of the tang capture feature inherently provides more isolation of the edge insulation area from contaminating agents. A greatly enhanced Non-Destructive Evaluation program for the RSRM has been incorporated. The enhanced non-destructive testing includes ultrasonic inspection and mechanical testing of propellant and insulation bonded surfaces. All segments will again be X-rayed for the first flight and near-term subsequent flights.

CONTINGENCY PLANNING. To provide additional program confidence, both near- and long-term contingency planning was implemented. Alternative designs, which might be incorporated into the flight program at discrete decision points, include field-joint graphite-composite overwrap bands and alternative seals for the field joint and case-to-nozzle joint. Alternative designs for the nozzle include a different composite lay-up technique and a steel nose inlet housing.

Alternative designs with long-lead-time implications were also developed. These designs focus on the field joint and cast-to-nozzle joint. Since fabrication of the large steel components dictates the schedule, long-lead procurement of maximum-size steel ingots was initiated. This allowed machining of case joints to either the new baseline or to an alternative design configuration. Ingot processing continued through forging and heat treating. At that time, the final design was selected. A principal consideration in this configuration decision was the result of verification testing on the baseline configuration.

INDEPENDENT OVERSIGHT. As recommended in the "Presidential Commission Report" and at the request of the NASA administrator, the National Research Council established an Independent Oversight Panel chaired by Dr. H. Guyford Stever, who reports directly to the NASA Administrator. Initially, the panel was given introductory briefings on the Shuttle system requirements, implementation and control, the original design and manufacturing of the SRM, Mission 51-L accident analyses and preliminary plans for the redesign. The panel has met with major SRM manufacturers and vendors, and has visited some of their facilities. The panel frequently reviewed the RSRM design criteria, engineering analyses and design, and certification program planning. Panel members continuously review the design and testing for safe operation, selection and specifications for material, and quality assurance and control. The panel has continued to review the design as it progresses through certification and review the manufacturing and assembly of the first flight RSRM. Panel members have participated in major program milestones, project requirements review, and preliminary design review; they also will participate in future review. Six written reports have been provided by the panel to the NASA administrator.

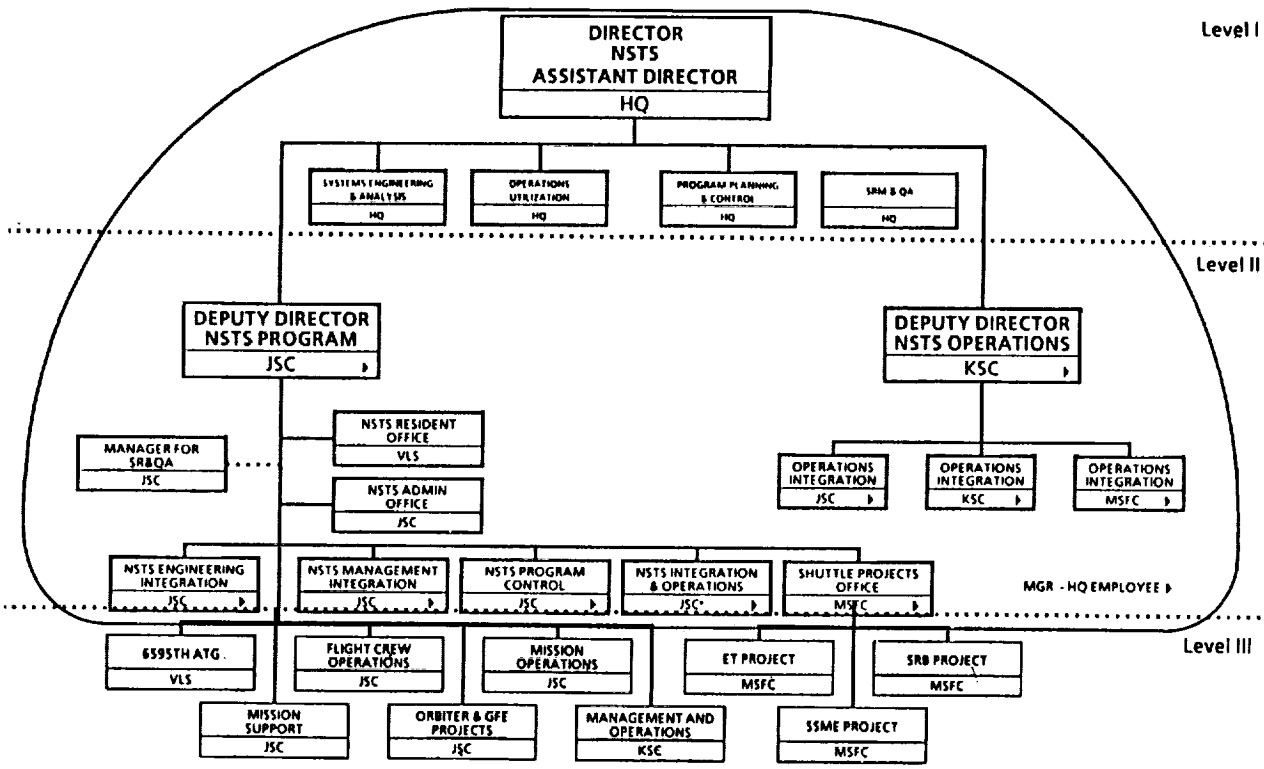
In addition to the NRC, the redesign team has a design review group of 12 expert senior engineers from NASA and the aerospace industry. They have advised on major program decisions and serve as a "sounding board" for the program.

Additionally, NASA requested the four other major SRM companies -- Aerojet Strategic Propulsion Co., Atlantic Research Corp., Hercules Inc. and United Technologies Corp.'s Chemical Systems Division -- to participate in the redesign efforts by critiquing the design approach and providing experience on alternative design approaches.

NSTS PROGRAM MANAGEMENT

The Space Shuttle program is the major segment of NASA's National Space Transportation System (NSTS) managed by the Office of Space Flight (OSF) at NASA Headquarters in Washington, D. C. The office is headed by an Associate Administrator who reports directly to the NASA Administrator and is charged with providing executive leadership, overall direction and effective accomplishment of the Space Shuttle and associated programs, including unmanned launch vehicles.

The Associate Administrator for Space Flight exercises institutional management authority over the activities of the NASA field organizations whose primary functions are related to the NSTS program. These are Johnson Space Center (JSC), Houston, Texas; Kennedy Space Center (KSC), Fla.; Marshall Space Flight Center (MSFC), Huntsville, Ala.; and Stennis Space Center (formerly National Space Technology Laboratories), Bay St. Louis, Miss.



NSTS Organization and Relationships

The directors of these organizations, along with the Associate Administrator for Space Flight, also are members of the Office of Space Flight Management Council. This group meets regularly to review Shuttle program progress and to provide an independent and objective assessment of the status of the overall program.

NSTS ORGANIZATION. Within the OSF, centralized management authority for the Space Shuttle program is charged to the Director, NSTS. This individual is the program's general manager and has full responsibility and authority for the operation and conduct of the Shuttle program. These responsibilities include program control, budget planning and preparation, scheduling and the maintenance of a balanced program. The NSTS director reports to the Associate Administrator for Space Flight.

Organizational elements of the NSTS office are located at NASA Headquarters, JSC, KSC, MSFC and at the Vandenberg Launch Site (VLS); in California.

The NSTS office has two deputies who are responsible for the day-to-day management and operation of the Shuttle program. They are: Deputy Director, NSTS Program, a NASA Headquarters employee whose duty station is at JSC, and the Deputy Director, NSTS Operations, also a NASA Headquarters employee, whose duty station is at KSC. Both individuals report directly to the NSTS director.

Specific major responsibilities of the Deputy Director, NSTS Program, include the following:

•Establishing policy and providing continuous direction to all elements engaged in Shuttle program activities.

•Establishing and controlling the Level II (two) requirements baseline that provides the detailed requirements that supplement and implement the Level I (one) requirements.

•Detailed program planning, budgeting, scheduling, system configuration management and program direction.

•System engineering and integration of the flight vehicle, ground systems and facilities.

•Integration of payloads with orbiter.o Mission planning and integration.

There are five organizational elements under the Deputy Director, NSTS Program, charged with accomplishing the management responsibilities of the program. They are: NSTS Engineering Integration, NSTS Management Integration, NSTS Program Control and NSTS Integration and Operations -- all of which are located at JSC. The fifth division is the Shuttle Projects Office, located at MSFC, which has overall management and coordination of the MSFC elements -- the solid rocket boosters, external tank and main engines -- involved in the Shuttle program.

The Deputy Director, NSTS Operations, on the other hand, is specifically charged with the following major functions:

•Formulating policy, program plans and budget requirements in support of Shuttle operations at KSC, JSC, Edwards AFB and Vandenberg AFB, as well as other program operations facilities including the worldwide contingency landing sites.

•Final vehicle preparation, mission execution and return of the orbiter for processing for its next flight.

•Management of the presentation and scheduling of the Flight Readiness Review (FRR).

•Chairing and management of the Mission Management Team (MMT).

The duties of the NSTS Deputy Director, Operations, are carried out by three Operations Integration offices located at JSC, KSC and MSFC.

Management relationships in the centralized NSTS organization are configured into four basic management levels which are designed to reduce the potential for conflict between the program organizations and NASA institutional organizations.

The NSTS Director serves as the Level I manager and is responsible for the overall program requirements, budgets and schedules.

The NSTS Deputy Directors are Level II managers and responsible for management and integration of all elements of the program. This includes integrated flight and ground system requirements, schedules and budgets.

NSTS project managers located at JSC, KSC and MSFC are classified as Level III (three) managers and are responsible for managing design, qualification and manufacturing of Shuttle components, as well as a launch and landing operations.

NSTS design authority personnel and contractors are Level IV managers and are responsible for the design, development, manufacturing, test and qualification of Shuttle systems.

LAUNCH CONSTRAINT PROCEDURES. As part of the FRR, a launch constraints list is established and approved by the Associate Administrator. The Deputy Director, NSTS Operations, has the responsibility to tract each of the constraints and to assure that they are properly closed out prior to the L-2 day MMT review. The Associate Administrator or his designee (Director, NSTS) has the final closeout authority.

LAUNCH DECISION PROCESS. Major decision-making meetings leading to a decision to launch are Flight Readiness Reviews and Mission Magament Team reviews.

The FRR is usually held 2 weeks before a scheduled launch. Its chairman is the Associate Administrator for Space Flight. Present at the review are all senior program and field organization management officials and support contractor representatives.

During the review, each manager must assess his readiness for launch based on hardware status, problems encountered during launch processing, launch constraints and open items. Each NASA project manager and major Shuttle component support contractor representative is required to sign a Certificate of Flight Readiness.

The MMT, made up of program/project level managers, and chaired by the Deputy Director, NSTS Operations, provides a forum for resolving problems and issues outside the guidelines and constraints established for the Launch and Flight Directors.

The MMT will be activated at launch minus 2 days (L-2) for a launch countdown status briefing. The objective of the L-2 day meeting is a assess any deltas to flight readiness since the FRR and to give a "go/no-go" to continue the countdown.

The MMT will remain active during the final countdown and will develop recommendations on vehicle anomalies and required changes to previously agreed to launch commit criteria. The MMT chairman will give the Launch Director a "go" for coming out of the L-9 minute hold and is responsible for the final "go/no-go" decision.

MANAGEMENT COMMUNICATIONS. In the area of management communications, weekly integrated program schedules are published which provide detailed data from each project element and the NSTS Engineering Office. These widely distributed schedules are designed to create management awareness of the interrelated tasks and critical program paths needed to meet important program milestones.

Additionally, all project and program management personnel meet monthly at the Program Director Management Review to brief the program status and to resolve any program issues and concerns. This review is followed by a meeting of the Management Council to also review status and to resolve any issues brought forward by the Director, NSTS.

CHRONOLOGY

1972

Jan. 5	President Nixon proposes development of a reusable space transportation system, the Space Shuttle.
March 15	NASA selects the three-part configuration for the Space Shuttle -- reusable orbiter, partly reusable SRB and an expendable external tank.
Aug. 9	Rockwell receives NASA contract for construction of the Space Shuttle orbiter.

1975

Oct. 17	First Space Shuttle main engine tested at the National Space Technology Laboratories, Miss.
Sept. 17	Rollout of orbiter Enterprise (OV-101).

1976

July 18	Thiokol conducts 2-minute firing of an SRB at Brigham City, Utah.
Aug. 12	First free flight Approach and Landing Test (ALT) of orbiter Enterprise from Shuttle carrier aircraft at Dryden Flight Research Center, Calif. Flight duration: 5 minutes, 21 seconds. Landing occurred on Runway 17.
Sept. 13	Second Enterprise ALT flight of 5 minutes, 28 seconds; landing on Runway 15. (Three more ALT flights were flown by Enterprise on Sept. 23 Oct. 12 and Oct. 25.)

1978

Jan. 18	Thiokol conducts second test firing of an SRB.

1979

March 8	Orbiter Columbia (OV-102) transported 38 miles overland from Palmdale to Dryden Flight Research Center.
March 20-24	Columbia flown on Shuttle carrier aircraft to Kennedy Space Center with overnight stops at El Paso and San Antonio, Texas, and Eglin AFB, Fla.
June 15	First SRB qualification test firing; 122 seconds.

1980

Nov. 26	Columbia mated to SRBs and external tank at Vehicle Assembly Building (VAB) for STS-1 mission.
Dec. 29	Space Shuttle vehicle moved from VAB to Launch Complex 39A for STS-1 mission.1981

1980 continued

Feb. 20	Flight readiness firing of Columbia's main engines; 20 seconds.
April 20-21	Columbia returned to KSC by Shuttle carrier aircraft via Tinker AFB, Okla.
Aug. 4	Columbia mated with SRBs and external tank for STS-2 mission.
Aug. 26	Space Shuttle vehicle moved to Launch Complex 39A for STS-2 mission.
Nov. 12-14	STS-2, first flight of an orbiter previously flown in space
Nov. 24-25	Columbia transported back to KSC via Bergstrom AFB, Texas.
Dec. 11	Spacelab 1 arrives at KSC.

1982

Feb. 3	Columbia moved to VAB for mating in preparation for STS-3 mission.
Feb. 16	Assembled Space Shuttle vehicle moved from VAB to launch pad for STS-3 mission.
March 22-30	STS-3 mission; landing at White Sands, N.M.
April 6	Columbia returned to KSC from White Sands.
May 16	Columbia moved to VAB for mating in preparation for STS-4.
May 25	STS-4 vehicle moved to launch pad.
June 27-July 4	STS-4 mission flown; first concrete runway landing at Edwards AFB.
June 30	Orbiter Challenger (OV-099) rolled out at Palmdale.
July 1	Challenger moved overland to Dryden.
July 4-5	Challenger flown to KSC via Ellington AFB, Texas.
July 14-15	Columbia flown to KSC via Dyess AFB, Texas.
Sept. 9	Columbia mated with SRBs and external tank in preparation for STS-5.
Sept. 21	STS-5 vehicle moved to launch pad.
Nov. 11-16	STS-5 mission; landing at Edwards AFB.
Nov. 21-22	Columbia returned to KSC via Kelly AFB, Texas
Nov. 23	Challenger moved to VAB and mated for STS-6.
Nov. 30	STS-6 vehicle moved to launch pad.
Dec. 18	Flight readiness firing of Challenger's main engines; 20 seconds.

CHRONOLOGY

1983

Jan. 22	Second flight readiness firing of Challenger's main engines; 22 seconds.
April 4-9	STS-6 mission, first flight of Challenger.
May 21	Challenger moved to VAB for mating in preparation for STS-7 mission.
May 26	Challenger moved to launch pad for STS-7.
June 18-24	STS-7 mission flown with landing at Edwards AFB.
July 26	Challenger moved to VAB for mating in preparation for STS-8.
June 28-29	Challenger flown back to KSC via Kelly AFB.
Aug. 2	STS-8 vehicle moved to launch pad.
Aug. 30-Sept. 5	STS-8 mission; first night launch and landing at Edwards AFB.
Sep. 9	Challenger returned to KSC via Sheppard AFB, Texas.
Sept. 23	Columbia moved to VAB for mating in preparation for STS-9.
Sept. 28	STS-9 vehicle moved to launch pad.
Oct. 17	STS-9 launch vehicle moved back to VAB from pad because of SRB nozzle problem.
Oct. 19	Columbia moved to Orbiter Processing Facility.
Nov. 5	Orbiter Discovery (OV-103) moved overland to Dryden.
Nov. 6	Discovery transported to Vandenberg AFB, Calif.
Nov. 8	STS-9 vehicle again moved to launch pad.
Nov. 8-9	Discovery flown from Vandenberg AFB to KSC via Carswell AFB, Texas.
Nov. 28-Dec. 8	STS-9 mission; landing at Edwards AFB.
Dec. 14-15	Columbia flown to KSC via El Paso, Kelly AFB and Eglin AFB.

1984

Jan. 6	Challenger moved to VAB for mating in preparation of STS 41 B mission.
Jan. 11	STS 41-B vehicle moved to launch pad.
Feb. 3-11	STS 41-B mission; first landing at KSC.
March 14	Challenger moved to VAB for mating in preparation for STS 41-C mission.
March 19	STS 41-C vehicle moved to launch pad.
April 6-13	STS 41-C mission; landing at Edwards AFB.

1984 continued

April 17-18	Challenger flown back to KSC via Kelly AFB.
May 12	Discovery moved to VAB for mating in preparation for STS 41-D.
May 19	STS 41-D vehicle moved to launch pad.
June 2	Flight readiness firing of Discovery's main engines.
June 25	STS 41-D launch attempt scrubbed because of computer problem.
June 26	STS 41-D launch attempt scrubbed following main engine shutdown at T minus 4 seconds.
July 14	STS 41-D vehicle moved back to VAB for remanifest of payloads.
Aug. 9	STS 41-D vehicle again moved out to the launch pad.
Aug. 30-Sept. 5	STS 41-D mission; first flight of Discovery;landing at Edwards AFB.
Sept. 8	Challenger moved to VAB for mating in preparation for STS 41-G mission.
Sept. 9-10	Discovery returned to KSC via Altus AFB, Okla.
Sept. 13	STS 41-G launch vehicle moved to launch pad.
Oct. 5-13	STS 41-G mission; landing at KSC.
Oct. 18	Discovery moved to VAB for mating in preparation for STS 51-A mission.
Oct. 23	STS 51-A launch vehicle moved to launch pad.
Nov. 7	STS 51-A launch scrubbed because of high shear winds.
Nov. 8-16	STS 51-A mission; landing at KSC.

1985

Jan. 5	Discovery moved to launch pad for STS 51-C mission.
Jan. 24-27	STS 51-C mission landing at KSC.
Feb. 10	Challenger moved to VAB for mating in preparation for STS 51-E mission.
Feb. 15	STS 51-E vehicle moved to launch pad.
March 4	STS 51-E vehicle rolled back to VAB; mission cancelled; payloads combined with STS 51-B.
March 23	Discovery moved to VAB for mating in preparation for STS 51-D mission.
March 28	STS 51-D vehicle moved to launch pad.
April 6	Atlantis (OV-104) rollout at Palmdale.

1985 continued	
April 10	Challenger moved to VAB for mating in preparation for STS 51-B mission.
April 12-19	STS 51-D mission; landing at KSC.
April 13	Atlantis ferried to KSC via Ellington AFB, Texas.
April 15	Challenger moved to launch pad for 51-B missing.
April 29-May 6	STS 51-B mission; landing at Edwards AFB.
May 10	Challenger transported back to KSC via Kelly AFB.
May 28	Discovery moved to VAB for mating in preparation for STS 51-G.
June 4	STS 51-G vehicle moved to the launch pad.
June 17-24	STS 51-G mission; landing Edwards AFB.
June 24	Challenger moved to VAB for mating in preparation for STS 51-F.
June 28	Discovery ferried back to KSC via Bergstrom AFB, Texas.
June 29	STS 51-F vehicle moved to the launch pad.
July 11	Refurbished Columbia moved overland from Palmdale to Dryden.
July 12	STS 51-F launch scrubbed at T-minus 3 seconds because of main engine shutdown.
July 14	Columbia returned to KSC via Offutt AFB, Neb.
July 29-Aug. 6	STS 51-F mission landing at Edwards AFB.
July 30	Discovery moved to VAB for mating in preparation for STS 51-I mission.
Aug. 6	STS 51-I vehicle moved to the launch pad.
Aug. 10-11	Challenger flown to KSC via Davis-Monthan AFB, Ariz.; Kelly AFB; and Eglin AFB.
Aug. 24	STS 51-I mission scrubbed at T minus 5 minutes because of bad weather.
Aug. 25	STS 51-I mission scrubbed at T-minus 9 minutes because of an onboard computer problem.
Aug. 27-Sept. 3	STS 51-I mission; landing at Edwards AFB.
August 29	Atlantis moved to launch pad for the 51-J mission.
Sept. 7-8	Discovery flown back to KSC via Kelly AFB.
Sept. 12	Flight readiness firing of Atlantis' main engines; 20 seconds.
Oct. 3-7	STS 51-J mission; landing at Edwards AFB.
Oct. 11	Atlantis returned to KSC via Kelly AFB.
Oct. 12	Challenger moved to VAB for mating in preparation for the STS 61-A mission.

CHRONOLOGY

1985 continued

Oct. 16	Challenger vehicle moved to the launch pad for STS 61-A mission.
Oct. 30-Nov. 6	STS 61-A mission; landing at Edwards AFB.
Nov. 8	Atlantis moved to VAB for mating in preparation for the STS 61-B.
Nov. 10-11	Challenger flown back to KSC via Davis-Monthan AFB, Kelly AFB and Eglin AFB.
Nov. 12	STS 61-B vehicle moved to the launch pad.
Nov. 18	Enterprise (OV-101) flown from KSC to Dulles Airport, Washington, D.C., and turned over to the Smithsonian Institution.
Nov. 22	Columbia moved to the VAB for mating in preparation STS 61-C.
Nov. 26-Dec. 3	STS 61-B mission landing at Edwards AFB.
Dec. 1	STS 61-C vehicle moved to launch pad.
Dec. 7	Atlantis returned to KSC via Kelly AFB.
Dec. 16	Challenger moved to VAB for mating in preparation for the STS 51-L mission.
Dec. 19	STS 61-C mission scrubbed at T minus 13 seconds because of SRB auxiliary power unit problem.
Dec. 22	STS 51-L vehicle moved to Launch Pad 39B.

1986

Jan. 6	STS 61-C mission scrubbed at T minus 31 seconds because of liquid oxygen valve problem on pad.
Jan. 7	STS 61-C mission scrubbed at T minus 9 minutes because of weather problems at contingency landing sites.
Jan. 10	STS 61-C mission scrubbed T minus 9 minutes because of bad weather at KSC.
Jan. 12-18	STS 61-C mission; landing at Edwards AFB.
Jan. 22-23	Columbia returned to KSC via Davis-Monthan AFB, Kelly AFB and Eglin AFB.
Jan. 27-28	STS 51-L launched from Pad B. Vehicle exploded 1 minute, 13 seconds after liftoff resulting loss of seven crew members.
Feb. 3	President Reagan announced the formation of the Presidential Commission on the Space Shuttle Challenger Accident, headed by William P. Rogers, former Secretary of State.
March 24	NASA publishes "Strategy for Safely Returning the Space Shuttle to Flight Status."
May 12	President Reagan appoints Dr. James C. Fletcher NASA Administrator.
July 8	NASA establishes Safety, Reliability Maintainability, and Quality Assurance Office.

1986 continued

July 14	NASA's plan to implement the recommendations of the Rogers commission was submitted to President Reagan.
Aug. 15	President Reagan announced his decision to support a replacement for the Challenger. At the same time, it was announced that NASA no longer would launch commercial satellites, except for those which are Shuttle-unique or have national security or foreign policy implications.
Aug. 22	NASA announced the beginning of a series of tests designed to verify the ignition pressure dynamics of the Space Shuttle solid rocket motor field joint.
Sept. 5	Study contracts were awarded to five aerospace firms for conceptual designs of an alternative or Block II Space Shuttle solid rocket motor.
Sept. 10	Astronaut Bryan O'Connor was named chairman of Space Flight Safety Panel. This panel, with oversight responsibility for all NASA manned space program activities, reports to the Associate Administrator for Safety, Reliability, Maintainability and Quality Assurance.
Oct. 2	After an intensive study, NASA announced the decision to test fire the redesigned solid rocket motor in a horizontal attitude to best simulate the critical conditions on the field joint which failed during the 51-L mission.
Oct. 30	Discovery moved to OPF where more than 200 modifications are accomplished for STS-26 mission.
Nov. 6	Office of the Director, National Space Transportation System, established in the NASA Headquarters Office of Space Flight.

1987

July 31	Rockwell International awarded contract to build a fifth orbiter to replace the Challenger.
Aug. 3	Discovery in the Orbital Processing Facility is powered up for STS-26 mission.

1988

Mid-Jan.	Main engines are installed in Discovery.
March 28	Stacking of Discovery's SRBs gets underway.
May 28	Stacking of Discovery's SRBs completed.
June 10	SRBs and External Tank are mated.
June 14	The fourth full-duration test firing of the redesigned SRB motor is carried out.
June 21	Discovery rolls over from OPF tp the VAB.
July 4	Discovery moved to Launch Pad 39B for STS-26 mission.
Aug. 10	Flight Readiness Firing of Discovery's main engines is conducted successfully.